DEVELOPMENT OF OPTICAL LIQUID LEVEL SENSOR

FOR USE IN LIQUID HYDROGEN

FINAL REPORT
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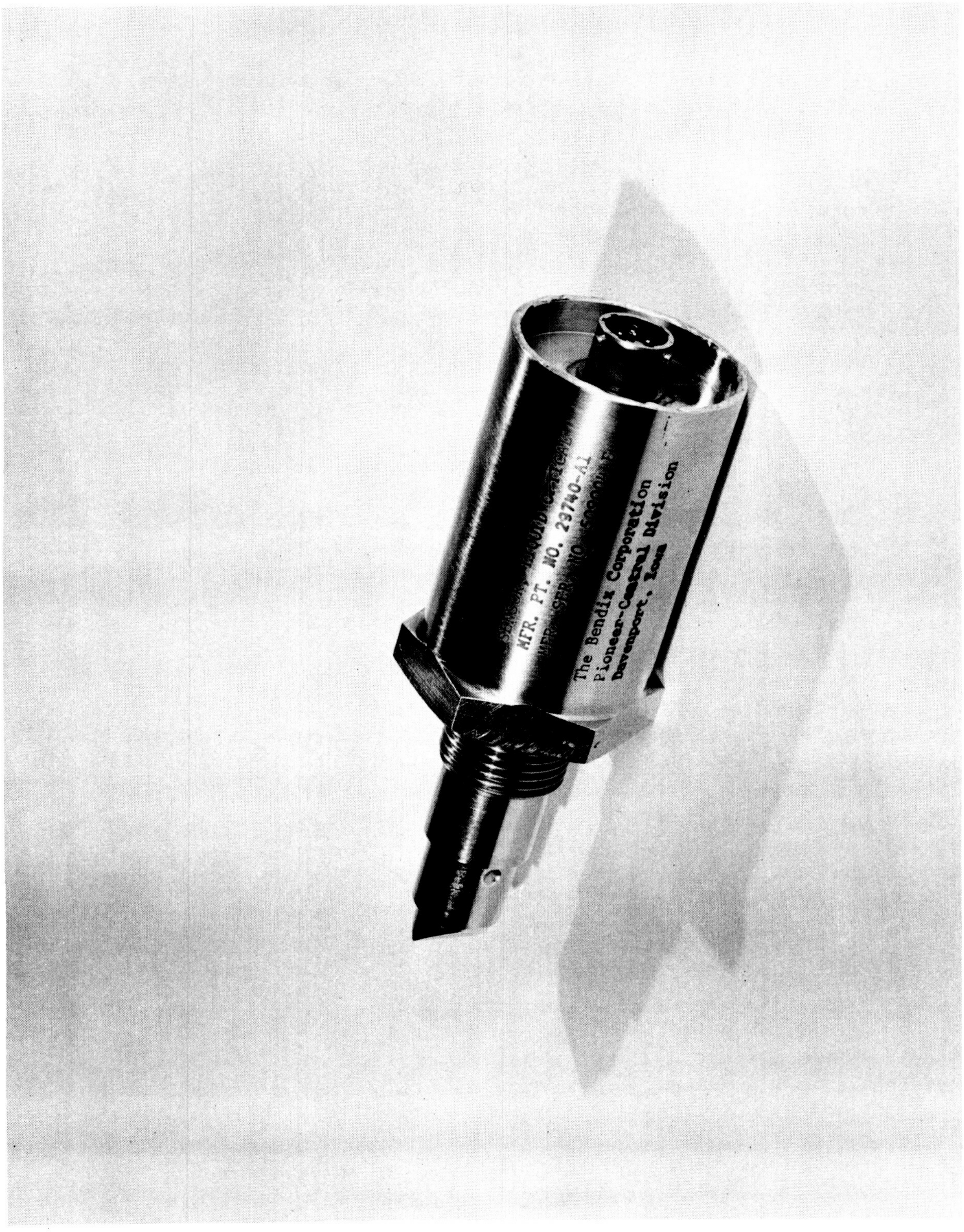


29740-A1 Optical Liquid Sensor

1.0 INTRODUCTION

This report describes a program conducted under NASA Contract No. NAS 8-11644 which involved the development of an optical liquid-level sensor specifically designed for use in liquid hydrogen in accordance with NASA Specification R-P & VE-PMS-SPEC-4-63, Revision A. The sensor developed under this contract has been designated Bendix Type No. 29740-A1.

The Pioneer-Central Division of The Bendix Corporation has developed optical liquid sensors which are operational in liquid oxygen and liquid nitrogen. These sensors are fabricated as a single unit, with both detection and amplification components packaged together without internal or external heater elements. The development work performed under this contract extends the capabilities of these sensors for operating at liquid hydrogen temperatures. The sensor uses solid state electronic components selected for operation at cryogenic temperatures.

The sensor operates over the temperature range of -255°C to +50°C, has a sensing accuracy of ± 0.1 inch and a response time of approximately 4 milliseconds. It operates from 28 vdc with a 200 ma. maximum current drain and furnishes an "in-liquid" or "out-of-liquid" electrical signal which may be used to switch an external 28 vdc load.

During sensor development, the operational characteristic of various electronic circuits and components were evaluated for satisfactory performance at liquid hydrogen temperatures. Data obtained during these investigations are reproduced in this report. In addition, comments and recommendations are given for future programs to further improve the sensor by reducing the size, weight, and power consumption of the units.

In conducting this program, the following tasks were performed:

(1) Test circuits were designed and tested which operate satisfactorily over the entire temperature range of -255°C to +50°C.

(2) The sensor was packaged using these circuits in a NASA-specified package envelope.

(3) A component-test program was conducted to determine the suitability of individual electronic components for this application.

(4) The completed hydrogen sensor package was tested in an LH_2 environment and at intermediate temperatures to an upper limit of +50°C.

2.0 ORGANIZATION OF THE PROGRAM

Study of the controlling NASA specification R-P&VE-PMS-SPEC-4-63, Revision A against the background of previous experience with cryogenic optical liquid sensors led to a breakdown of the program into the following tasks:

1. Determine the basic unit design to be developed.
2. Set up design guidelines for circuitry design.
3. Perform Component Survey to determine which components could be used and how their parameters would influence circuit design.
4. Complete development and testing of circuit blocks.
5. Integrate the developed and tested circuit blocks into a complete circuit.
6. Develop unit package.
7. Build and test prototypes of the complete unit.
8. Make any changes indicated by the test program and retest.
9. Fabricate and test three units for delivery.

During the course of accomplishing the above tasks, several technical milestones were passed which were necessary to the progress of the program. The major milestones with their completion dates are shown here.

	Milestone	Approximate Completion Date
1.	Starting date	June 1964
2.	Determination of acceptable transistors for use in circuit design work	August 1964
3.	Development of acceptable oscillator circuits	September 1964
4.	Development of acceptable ac amplifier circuits	September 1964
5.	Development of acceptable detector and dc amplifier circuits	September 1964
6.	Testing of complete breadboard unit at LH_2 temperature	November 1964
7.	Completion of package design	February 1965
8.	Successful testing of completely packaged prototype	May 1965
9.	Completion of testing and shipment of three sensors	October 19, 1965

The dates listed on the preceding page indicate the time of completion of the major work in the area. There was some interruption in the work for contract reasons. In some cases it was necessary to perform some redesign and do some additional work after the dates listed, but the work in this category was comparatively minor in relationship to the program.

3.0 PRINCIPLE OF 29740-A1 SENSOR OPERATION

3.1 OPTICAL PRINCIPLES

The basic principle of operation of the Bendix Optical Liquid Sensor is shown in Figure 3-1.

Light rays from an internal light source are directed down one side of a transparent cylindrical prism. The end of the prism is located at the point at which the presence or absence of liquid is to be sensed. If liquid is present at the end of the prism, the light passes out of the prism and is dissipated in the liquid. If the liquid is not present at the end of the prism, the light is internally reflected in the prism and is transmitted back through the prism where it strikes a solar cell. The output of the solar cell drives a transistorized amplifier which in turn switches an output transistor to the "no liquid" condition.

The optical switching principle is based on the phenomena of refraction and reflection of light. The physical law governing this phenomena is expressed as:

$$\text{Sin } R = \frac{V_L}{V_A} \text{ Sin } I \qquad \text{(Equation 3.1.1)}$$

Where:

Sin R = sine of the angle of refraction.

V_L = velocity of light in the medium in which it leaves the interface.

V_A = velocity of light in the medium in which it arrives at the interface.

Sin I = sine of the angle of incidence.

The angles of refraction and incidence are measured from a perpendicular to the interface.

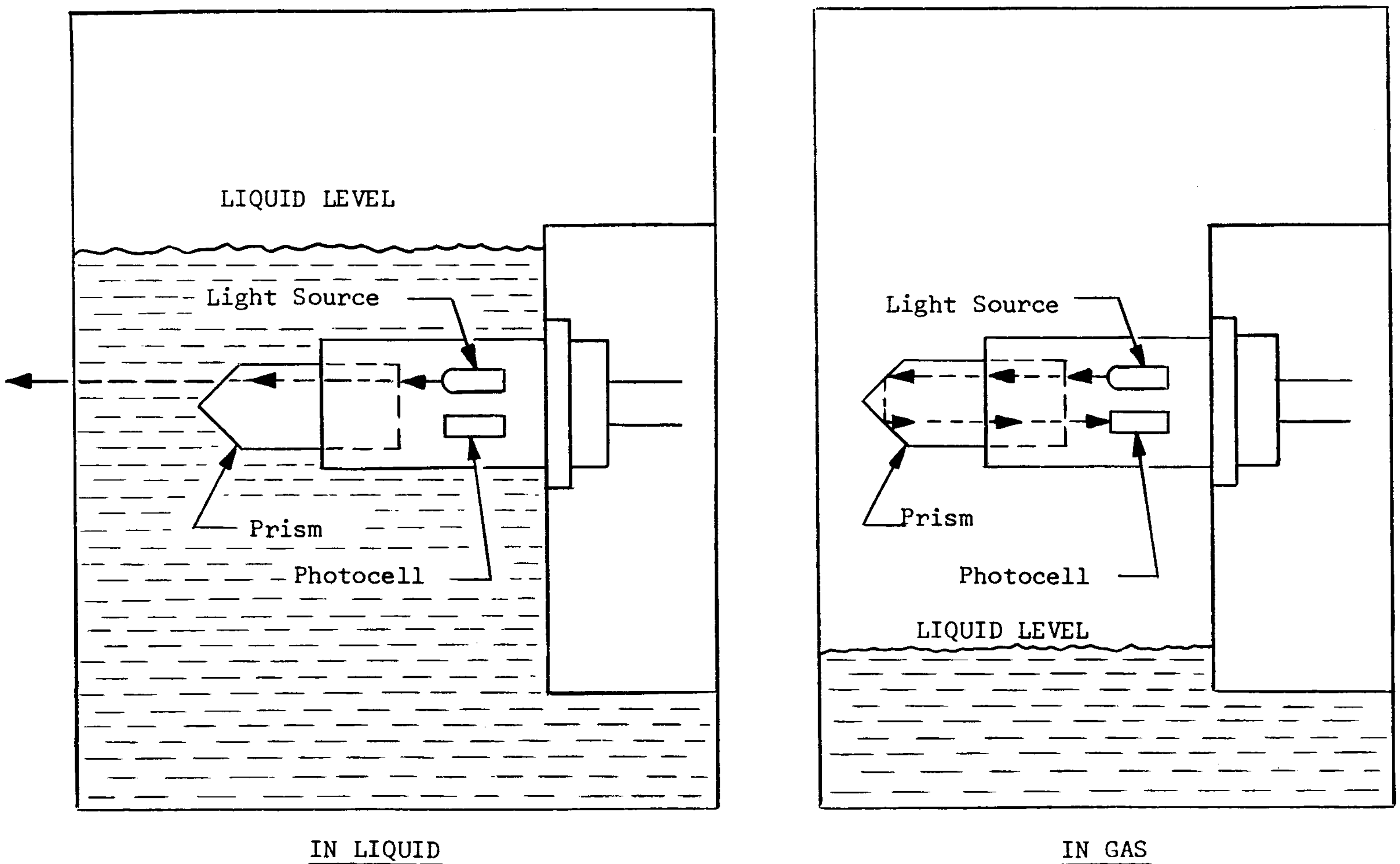
The law is often expressed in terms of indices of refraction. The index of refraction of a medium is defined as the velocity of light in a vacuum divided by the velocity of light in the medium. Hence, Equation 3.1.1 can be re-written as:

$$\text{Sin } R = \frac{K_A}{K_L} \text{ Sin } I \qquad \text{(Equation 3.1.2)}$$

Where:

K_A = index of refraction of material through which light arrives at the interface.

K_L = index of refraction of material through which light leaves the interface.



PRINCIPLE OF LIQUID DETECTION
OPTICAL LIQUID LEVEL SENSOR

Figure 3-1.

A graphical representation of this phenomen is shown in Figure 3-2.

A series of plane wave fronts are arriving at, and leaving, an interface A-B which contains a point X. The wave fronts approach the interface along line a at an angle of incidence I which is measured between the line a and the line b. Line b is perpendicular to the interface.

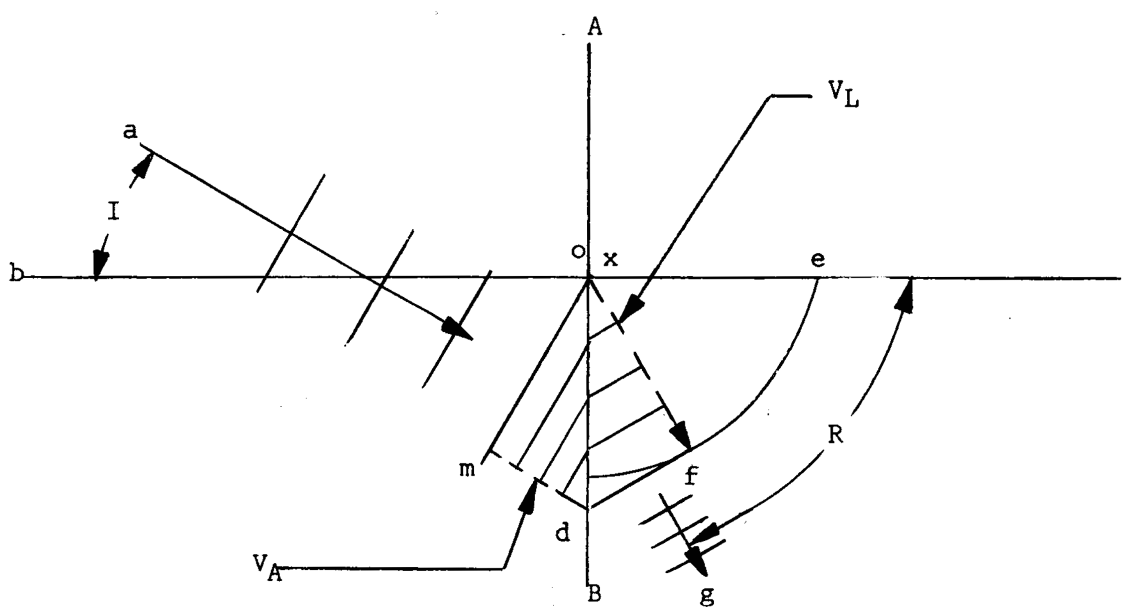


Figure 3-2.

At the instant shown, a wave front defined by the line o-m is intersecting the point X. As the wave front o-m continues it arrives at a point d located on the interface A-B.

The line m-d has a direction of movement toward the interface A-B. For convenience let the length of m-d represent the velocity of the wave front arriving, V_A. Further, let the velocity of the wave front leaving, V_L, to the right of the interface A-B be one and one half times the velocity V_A in the medium to the left of the interface A-B. Then the motion of the wave front o-m during the period when it traverses the line m-d to the point d, can be described by a vector one and one half times the length of line m-d. This tendency begins at the point X on the interface A-B and continues to the arc e described as a radius which is one and one half times the length of line m-d.

At the end of that period, the wave front o-m will extend through d and will be tangent to arc e and will lie on arc e at the point of tangency f. The wave will move in the direction of line g at the refraction angle R.

Inspection of Equation 3.1.2 will show that it is possible for the magnitude of the right side of the equation to exceed "1" for certain conditions of media, thus making the equation invalid. This results in refraction becoming impossible when the Sin R tends to exceed "1". Therefore, under these conditions the wave must be entirely reflected.

This means that there will always be refraction if the velocity of light in the medium through which it arrives, V_A (at the interface) exceeds the velocity of light in the medium through which it leaves, V_L, (the interface). On the other hand, if, in Figure 3-2, the velocity is increased so that arc e passes through point d, no light will be refracted. Instead, all the light arriving at the interface will travel downward along the interface. The angle I shown would be the critical angle of this modified ratio of "arriving" and "leaving" light velocities.

If the angle of incidence is increased without change in either of the velocities, the situation can be represented by moving point d toward point X so that the length of the V_A vector remains unchanged. In this case, the radius of arc e is greater than the distance x-d making it impossible to draw a tangent to the arc which will extend through point d. This means that the right side of the equations have a magnitude exceeding "1" and that all of the light will be reflected from the interface.

Therefore, the light will either be totally internally reflected in the prism or totally transmitted into the liquid. Thus, the presence or absence of liquid at the prism end is detected by a positive light switch which provides the high signal ratio from the photocell.

This light switching principle is effective in practically all liquids, including liquid hydrogen, liquid oxygen, RP-1 and water, and was utilized in the type 29740-A1 sensor developed in this program.

3.2 CIRCUIT OPERATING PRINCIPLES OF THE 29740-A1 SENSOR.

The signal generated by the photocell described on the preceding page is detected, amplified and used to drive the output transistor. This circuitry was designed to operate under the specified environmental conditions.

Because of the high vibration levels specified for this sensor, a light-emitting diode (LED) is incorporated as the light source rather than incandescent lamps.

Since the light levels produced by the LED are low it was necessary to modulate the LED to permit the use of ac coupling and amplification. The ac amplified signal is then detected and further amplified in a dc amplifier to drive the output transistor. (See figure 4-3 for a func- functional block diagram of the sensor.)

4.0 CIRCUIT DESIGN

4.1 CIRCUIT DESIGN GUIDELINES

The guidelines which were set up for the circuit design phase of the program resulted from an analysis of the requirements set forth in the controlling specification. A brief discussion of the major guidelines are listed in the following paragraphs.

4.1.1 Light Source Requirements

The vibration input level (specified at 50 g) ruled out the use of incandescent lamp light sources. Previous experience at Pioneer-Central has placed the upper vibration level at approximately 25 g for ruggedized lamps which had been especially developed for sensor applications. In earlier sensor programs, light-emitting diodes had been used successfully at vibration levels above 100g. It had also been determined that light-emitting diodes have the excellent life and reliability characteristics normally found in solid-state devices, even those operated at cryogenic temperatures. Therefore, a gallium-arsenide light-emitting diode was used as the light source in the 29740-A1 sensor.

4.1.2 Photocell Requirement

Both photovoltaic and photoresistive photocells have been used in optical liquid sensors. Although photoresistive cells have greater sensitivity than photovoltaic types, they tend to have poor stability and long time response at cryogenic temperatures. Considerable experience has been accumulated with boron-doped silicon solar cells in cryogenic sensor applications. Their response time is in the microsecond range and their temperature stability is very good when properly used. Therefore, this type of cell was used in the 29740-A1 sensor. (See paragraph 6.2.3 for further details on cell construction.

4.1.3 Amplifier Requirements

Items 4.1.1 and 4.1.2 above resulted in a combination which produces an output voltage of approximately 4 millivolts peak to peak under worst-case conditions when used in conjunction with the anticipated sensor prism design. This established the signal level which was available to drive the amplifier.

Because of the low signal level, it was not practical to design a DC amplifier or detector with adequate stability over this temperature range to operate directly from the photocell output. Therefore, an AC amplifier was required to raise the signal to a level at which detection could be performed reliably. A minimum of AC amplification was to be incorporated because of the larger number of parts required per unit gain as compared to the DC amplification which is possible after detection. It was estimated that a reasonable detection voltage would be approximately four volts peak-to-peak. This would permit detection to be accomplished in spite of the changes in diode and transistor characteristics over the temperature range. Thus, a voltage gain of approximately 1000 was required before detection. (See paragraph 4.3.2 for details of ac amplifier design.)

4.1.4 Detector Requirements

It was evident that detection would need to be accomplished with high efficiency and in such a way that temperature-dependent variables of circuit components would not cause large variations in operation. It was also necessary to integrate the detected AC signal sufficiently to drive a DC amplifier reliably over the temperature range. At the same time, the integration could not be so long as to seriously increase the response time for the sensor as a whole. (Discussion of the detector design is set forth in paragraph 4.3.3.)

4.1.5 DC Amplification and Output Stages

It was necessary to provide sufficient DC amplification to drive the output stage from the detector output with all components operating at LH_2 temperatures. It was anticipated that this part of the circuit could be a modification of earlier circuits which had been developed for use at LN_2 temperatures.

Figure 4-3 shows a block diagram of the sensor which was developed as a consequence of the above guideline requirements.

4.2 SUMMARY OF RESULTS OF COMPONENT SURVEY

Component testing was done in two categories during the program. Before specific circuit design work could be done, it was necessary to test circuit components to determine which were functional over the temperature range. It was then necessary to establish the parameter characteristics of those parts which were functional.

Later in the program, more extensive testing was done to establish confidence in the use of the components at LH_2 temperature. The scope of this program did not permit extensive reliability testing on components in the usual sense.

A general discussion of component test results is presented here. Specific test results are presented in Appendix I.

4.2.1 Capacitors

Previous studies of various capacitor types at LN_2 temperature had led to the selection of dry-electrolytic tantalum and silver-mica types for cryogenic service. Sufficient testing was done in this program to verify that their operating temperature range could be extended to LH_2 temperature. It was determined that both types of capacitors showed less than 10% change in capacitance from room temperature values. In the case of the dry-electrolytic tantalum capacitors, dissipation characteristics were essentially unchanged.

Since the capacitor requirements of the sensor circuitry were met by these two types of capacitors, no more capacitor testing was done.

FUNCTIONAL BLOCK DIAGRAM
OF THE OPTICAL LIQUID SENSOR

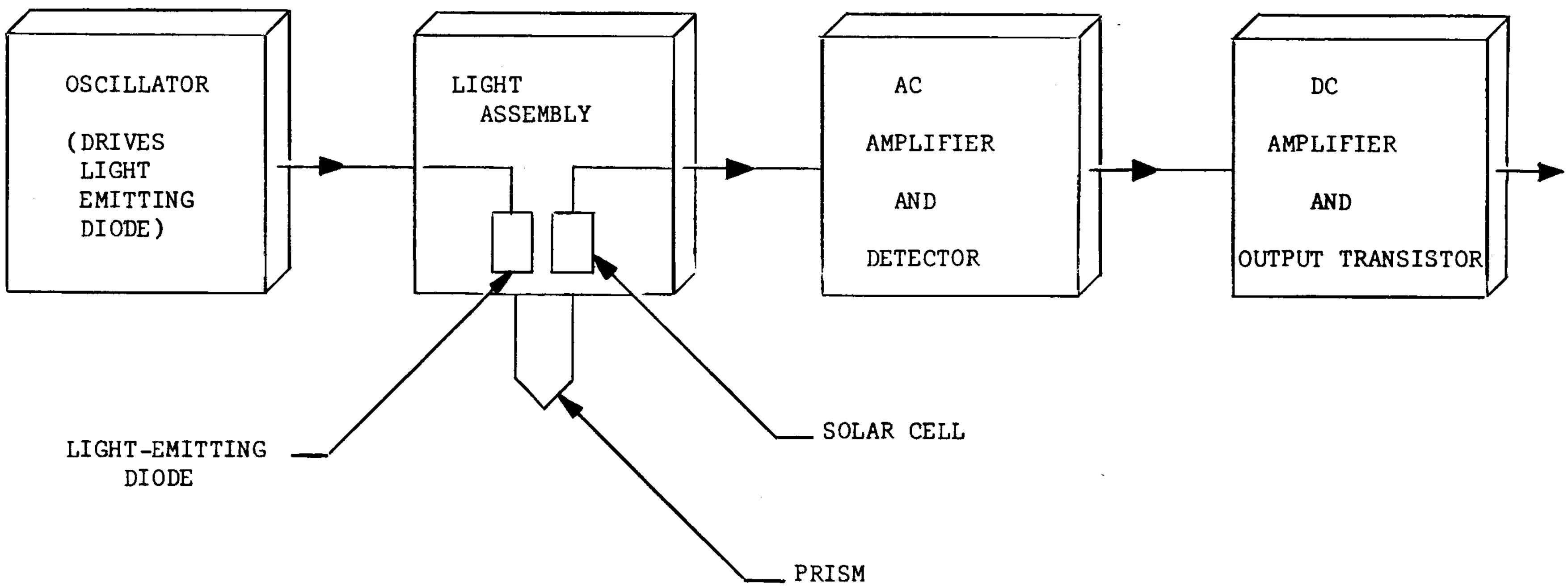


Figure 4-3.

4.2.2 Resistors

Both wirewound and metal-film resistors had been used extensively at cryogenic temperatures by Pioneer-Central with good results. Consequently, these types were selected for further testing in this program. Composition resistors were also tested.

The wirewound resistors were determined to be reliable over the temperature range and showed a resistance change on the order of 1%. A problem was encountered with the metal-film resistors during the course of the program. Although the resistance values were very stable, an occasional resistor developed an open circuit condition. This was traced to a characteristic of the 1/10 watt unit which had been selected to conserve space. Earlier experience has been with 1/8 watt units which were constructed differently. Therefore, the reliability of the 1/10 watt resistors which are incorporated in the three delivered sensors is not as high as desired. However, because of the extensive testing done on these sensors it is anticipated that they will remain operational during the remainder of the test program.

Composition resistors were determined to have a negative temperature coefficient of resistance. The percentage change in resistance value varies with the nominal value of the resistor and is greatest for high value resistors. Resistance increases for high value resistors exceeds 200% of room temperature value when tested at LH_2 temperatures. Composition resistors were considered only for temperature compensation purposes in the sensor circuit.

4.2.3 Transistors

Earlier experience with transistors at LN_2 temperatures had established the following points:

1. Germanium transistors maintain gain characteristics to a greater degree than silicon transistors as temperatures are reduced to the cryogenic range.

2. Silicon transistors using mesa construction retain useable gain down to the LN_2 temperature range. Planar units are unuseable at LN_2 temperature.

In view of this background, small numbers of several transistor types were subjected to preliminary tests at LH_2 temperature. (See Table I.) Results of this test led to quantity testing of 7 types. (See Table II for results of secondary tests.) Also, see Appendix I for photographs of typical transistor curve-tracer curves taken at room and LH_2 temperatures.

As a result of transistor tests, three types -- the 2N1308, 2N1309 and the 2N1039 -- were selected as being most suitable for use at LH_2 temperature. All are germanium transistors made by Texas Instruments. All three types are made by the alloy-junction process. Their comparatively better gain at LH_2 temperatures is attributed to the higher mobility of carriers in the junctions of these temperatures.

TABLE I

LIST OF TRANSISTORS TESTED AT LH_2 TEMPERATURE DURING PRELIMINARY TESTS

	TRANSISTOR	MFR.	DESCRIPTION	SAMPLES TESTED
Germanium	2N404A**	TI	PNP Alloy, Switching	4
	2N711B**	TI	PNP Alloy-Germanium Mesa	3
	GA-733**	TI	PNP Alloy-Junction	4
	2N1039**	TI	PNP Alloy-Junction	5
	2N1308**	TI	NPN Alloy-Junction	3
	2N1309**	TI	NPN Alloy-Junction	5
	2N2189**	TI	PNP Alloy-Diffused Mesa	3
	2N388A	TI	NPN Alloy-Junction	4
	2N652A	TI	PNP Alloy-Junction	3
Silicon*	2N2608	Siliconix	N Channel Field-Effect	3
	2N3277	Siliconix	P Channel Field-Effect	3
	CG-1	National	NPN Mesa	3
	2N760A	TI	NPN Double-Diffused Mesa	
	2N2985	TI	NPN Triple-Diffused Mesa	1

*All silicon transistors failed at LH_2 Temperature.

** These germanium transistors showed some gain and were included in secondary tests of larger quantities.

TABLE II

GAIN AVERAGES FOR TRANSISTORS TESTED
AT LH_2 TEMPERATURES DURING SECONDARY TESTS

	Room Temperature				LH_2 Temperature			
	h_{fe}	h_{FE}	h_{fe}	h_{FE}	h_{fe}	h_{FE}	h_{fe}	h_{FE}
TYPE	1V	10MA	5V	1MA	1V	10MA	5V	1MA
2N404A	84	60.8	--	--	22	12.8	12	5.7
2N711B*	113.3	62.7	--	--	24.4	10.3	30.3	17
GA-733	100.6	83.6	111.6	101.3	10.3	3.6	4.9	2.5
	1V	10MA	1V	100MA	1V	10MA	1V	100MA
2N1039*	88	73.6	76	65	2.56	1.37	8.3	5.5
2N1308*	207	163	147	139	16	11.8	7.8	6.7
2N1309*	197	175	195	183	20.3	12.1	13.3	6
2N2189*	190	125	110	80	57	22.4	15.9	11

* Selected for further tests.

The 2N1308, an npn transistor, and the 2N1309, a pnp transistor, were chosen for all functions where power levels were low. The 2N1039, a 20-watt device, was chosen for use in the output stage and for pulsing the light-emitting diode (LED).

As a result of the above tests, it was concluded that the 2N1308 and 2N1309 could be expected to maintain a current gain of 5 or more in low powered circuits. The 2N1039 could be expected to maintain a current gain of 2 or more in higher powered circuits. The establishment of these minimum values was a necessary step before proceeding to the circuit design phase.

It was apparent that the changes in base to emitter voltage characteristics could be designed around. It was also apparent that the normal high leakage characteristics of germanium transistors would need to be considered. However, the major consideration in circuit design would be in providing for normal operation while transistor gain changed drastically, sometimes as much as 20 to 1 over the temperature range.

4.2.4 Diodes

Standard silicon forward diodes and zener regulator diodes had been used extensively at LN_2 temperatures prior to this program with very good results.

The change in forward diodes which is of most importance is the forward voltage drop which increases as temperatures are reduced. This is an extension of the change encountered over more normal temperature ranges. Forward voltage drop increases from approximately .7 volts at room temperature to approximately 1.2 volts at LH_2 temperature depending upon the current being conducted. This change was used for temperature compensation in the circuit design. It was also found that leakage currents were greatly reduced at LH_2 temperatures.

Zener diodes were found to function normally at LH_2 temperatures with temperature coefficients related to nominal operating voltage. Alloy zeners in the 5 to 6 volt range were found to have very little change with temperature. Diffused diodes were more temperature dependent with higher voltage units showing a greater percentage voltage drop at LH_2 temperature.

Photographs of forward and zener diode curves are included in appendix 1.

The component test results summarized above provided the component information which was used in the circuit design phase of the program.

4.3 CIRCUIT BLOCK DEVELOPMENT

With circuit requirements as outlined in paragraph 4.1 and with component capabilities established as in paragraph 4.2, it was possible to proceed with development of the circuit. It was decided to design, build, and test the circuit by blocks to facilitate analysis and testing. (See

Figure 4-3.) A discussion of the development of each circuit block is presented here. In addition to the restrictions imposed by component limitations (primarily transistor gain and leakage), it was necessary to minimize the number of components because of space limitation.

4.3.1 Oscillator and LED Driver

Several variations of two basic types of oscillators were investigated. The first, the blocking oscillator (shown in Figure 4-4), was discarded because the frequency varied excessively with transistor gain and therefore with temperature. Also, the frequency was sensitive to reactive parameter changes. This approach was complicated by the need for high frequency operation because of response time requirements.

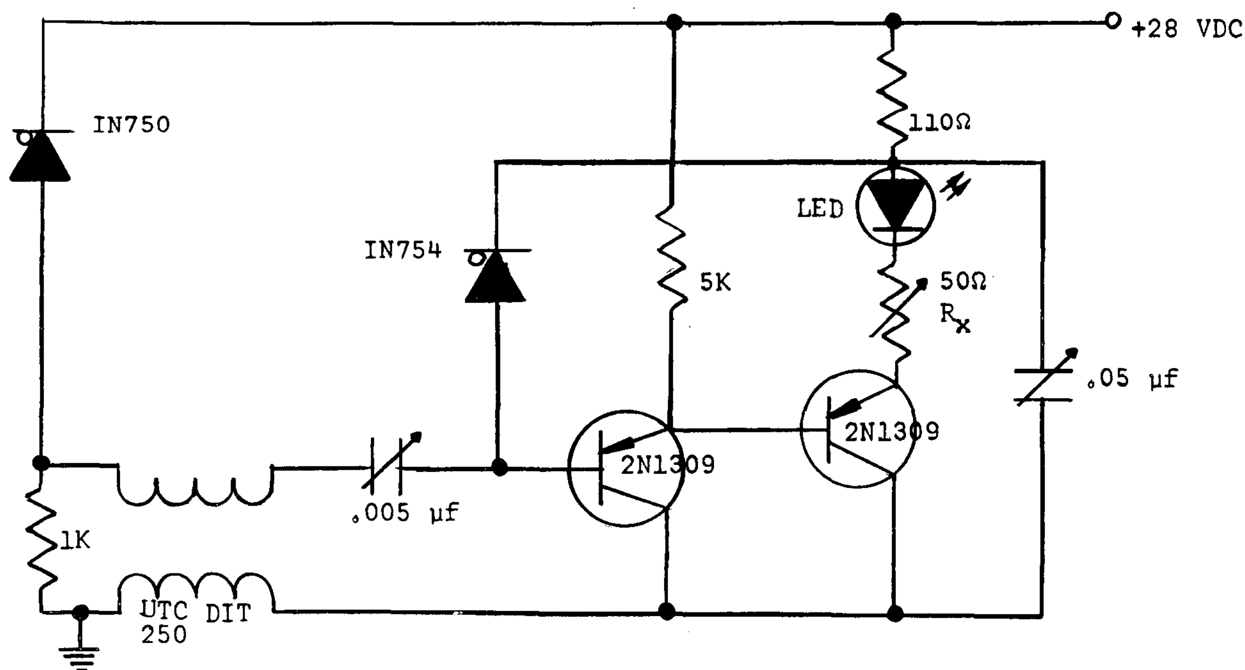


Figure 4-4. Blocking Oscillator

In addition to the blocking oscillator circuit, other oscillator circuits were investigated. However, most of the work was done on astable multivibrators. While this type of oscillator uses more components than the blocking oscillator, it has several advantages which make it desirable for this application. The duty cycle of the multivibrator is more nearly 50% and can be more easily controlled. The frequency is essentially independent of transistor gain and does not appreciable vary with temperature. The circuits of Figures 4-5 and 4-6 are examples of multivibrators investigated.

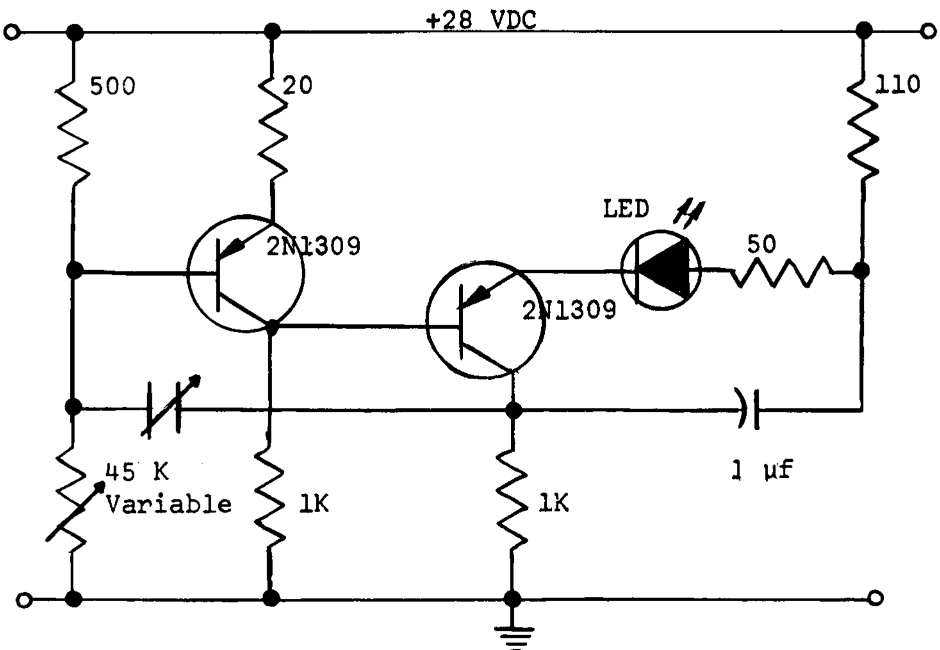


Figure 4-5. Preliminary Multivibrator Circuit

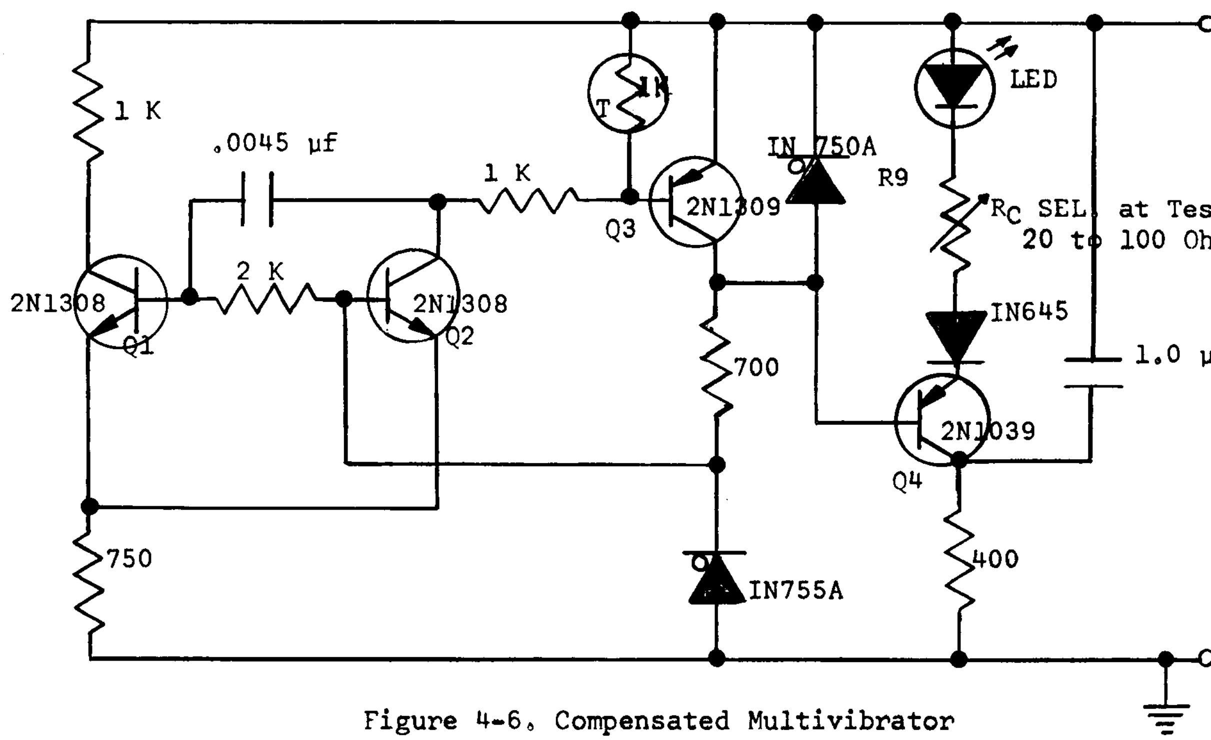


Figure 4-6. Compensated Multivibrator

The first approach was to allow one side of the multivibrator to pulse the LED, which could eliminate several components. However, this meant that either the astable multivibrator would be unbalanced with high current in one side or a balancing current could be added to the other side, causing the sensor to consume more power. It was decided that the addition of the required components would be desirable rather than have either of the above conditions.

The collector current of one side of the multivibrator, Figure 4-6, was amplified and used to drive the power stage which pulses the LED. A capacitor was added to create a low impedance path to allow high peak current through the LED. Usually, this was adjusted for 150 to 200 milliamps peak current. Adjusting R_c controlled the light emitted by the LED and, hence, the sensitivity of the sensor. The circuit was designed so that it would operate when the transistors had worst-case minimum gain.

For operation at high temperature, the leakage current of the driver transistor (Q_3) was compensated so that Q_3 would not cause Q_4 to be saturated or cut off. This was done by using a thermistor across the base-emitter junction of Q_3. At high temperatures, the thermistor has a low value and provides a path for leakage current. At cryogenic temperature, the thermistor is essentially an open circuit and does not degrade operation.

One other form of compensation was necessary in this portion of the circuit. The light-emitting diode used in this sensor has a temperature coefficient such that at LN_2 temperature, its output is considerably greater than at room temperature. At LH_2 temperature, its output is even higher. Thus, some method was needed to minimize this change. The resistor in series with the LED (R_c) was changed to a carbon composition resistor. Since this type of resistor increases in value approximately 200% at LH_2 temperature, the current through the LED is decreased by at least 50% and the light output is decreased accordingly.

4.3.2 AC Amplifier

In addition to the gain and leakage problems outlined previously, voltage drop across the diodes and transistor junctions at hydrogen temperatures also required compensation to avoid degradation of the amplifier performance. Several types of amplifiers with an assortment of transistor and feedback combinations were built and tested. The objective was to determine which type of circuit would provide the most ac gain and ac and dc stability across the temperature range with the least number of components.

Under worst-case conditions, the output of the solar cell was known to be 4 millivolts. With an estimated need of 4 volts out of the amplifier, the minimum gain of the amplifier had to be 1000. Using 2N1308 and/or 2N1309 transistors with a worst-case minimum beta of 5, a minimum of five transistors were required in the amplifier circuit.

It was decided to dc couple as many stages as possible to reduce the number of components. However, it soon became obvious that to maintain good bias stability using this approach, the amount of feedback necessary decreased the gain below a practical level.

Finally, a PNP, NPN, PNP amplifier circuit was designed as shown in Figure 4-7. The ac gain and dc stability of this circuit were reasonably good. However, because of problems at high temperature, it was temporarily discarded. Later, after some modification to reduce ac feedback through the regulator and bias circuitry, it was tested with satisfactory results from +65°C to -196°C. This basic ac amplifier circuit was used in the final design of the sensor.

Each section was designed to demand a minimum gain of five from the transistors. The overall voltage gain of each section is approximately fifty, thus giving a total available gain of 2500 with two sections in cascade.

A large amount of negative feedback was used to minimize the effect of large changes in current gain of the transistors. The resistor-capacitor bypass was put in to increase the ac gain of the circuit without affecting the dc stability. Originally, the resistors in series with the bypass capacitors were carbon composition types. This was done to decrease the ac gain at liquid hydrogen temperature to partially compensate for the increased output of the LED. However, later it was discovered that this was unnecessary and the carbon composition resistors were replaced with one percent wirewound resistors.

The diodes in the bias network of each section were put in to compensate for voltage changes across the junctions of the transistors. The thermistors were added to compensate for leakage currents at room and high temperatures. Since at these temperatures the transistors have very high gain, the thermistors do not cause appreciable signal degradation. At cryogenic temperatures when transistor gain is very low, the thermistors have essentially infinite resistance and therefore do not affect circuit operation.

Tests at temperatures ranging from +50°C to -250°C revealed the dc bias to be quite stable. A shift of only two volts around the design center was noted. The ac voltage gain also remained within the design limits.

4.3.3 Detector

Stability of the detector stage is very important since it is this stage that determines the switching characteristics of the sensor. Basically, this stage detects an ac input signal and converts it to a dc level output by integration. The dc level determines the switch point of the sensor and is a function of the amplitude of the input ac signal. To establish a stable switch point a constant threshold level must be maintained in the detector stage.

The first work with detector stages was done with circuits similar to other cryogenic sensors of this type. However, it soon became evident that a simple diode or transistor detector circuit was impractical with germanium transistors. In order to prevent leakage in the detector stage, it was necessary to provide a low impedance between base and emitter of the detector transistor. This led to excessive signal attenuation. The next step was to investigate transformer coupling which permits good bias

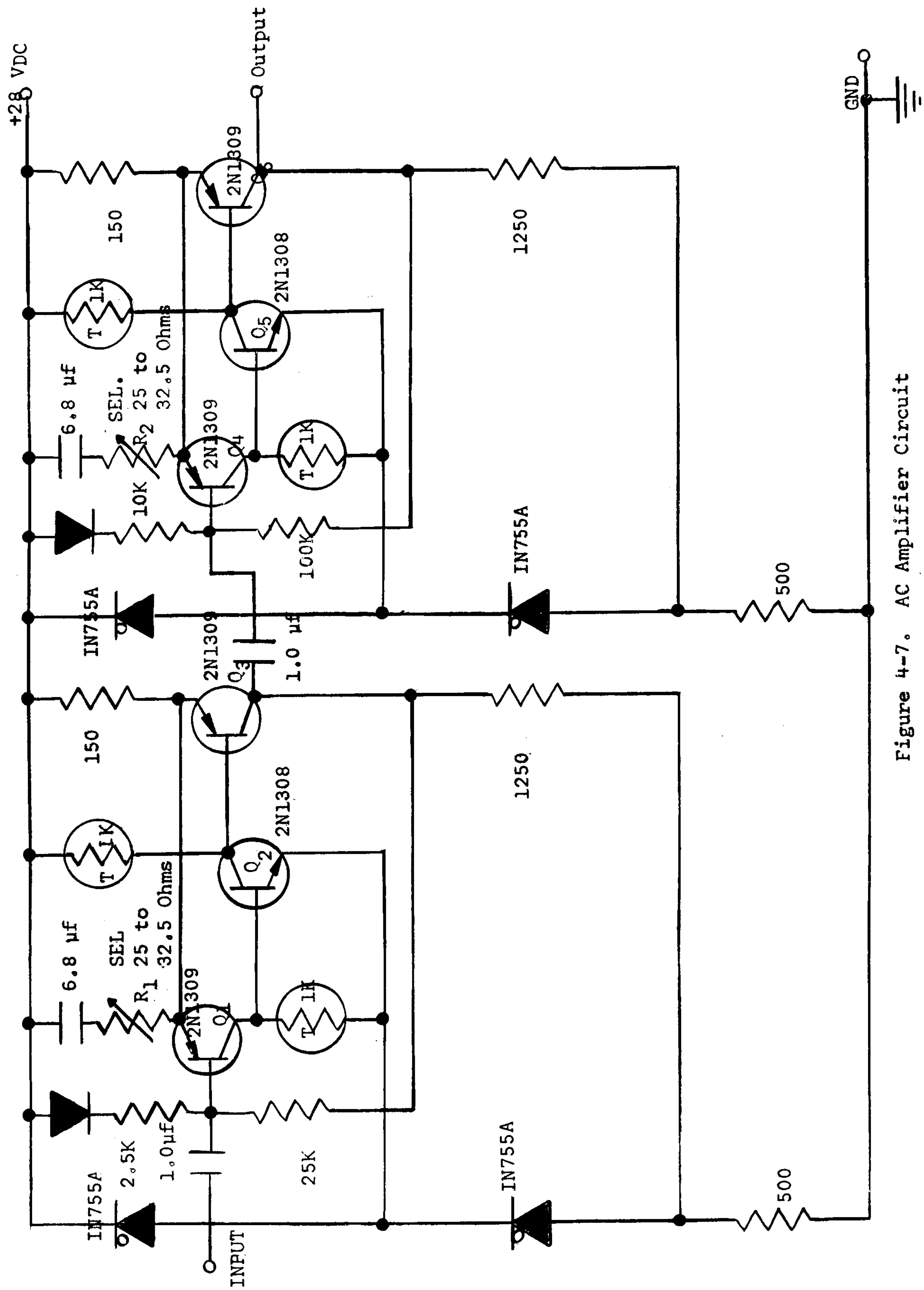


Figure 4-7. AC Amplifier Circuit

control and at the same time allows good ac signal coupling into the stage.

Various methods of transformer-coupling and transistor circuits were investigated. One circiut configuration that worked very well consisted of two transistors connected in a "push pull" arrangement. The output was a dc level which was filtered and amplified by a third stage. This circuit operated very well across the specified temperature range. However, it had one disadvantage in that it required a large number of components.

It was then decided to go back to the original transformer coupled detector stage and add another stage of gain. This circuit also worked well over the temperature range and required fewer parts than the "push pull" type circuit. This stage did not require temperature compensation since none of the temperature dependent variables affected operation appreciably. See Figure 4-8 for final circuit.

4.3.4 DC Amplifier and Output Stages

The dc amplifier and output stages are similar to circuits used in other cryogenic sensors. The circuits are straightforward dc switching amplifiers designed around the leakage and gain characteristics of the germanium transistors. Comparatively little effort was required in developing this circuit. See Figure 4-8 for final circuit.

4.3.5 RFI Filter

An RFI filter was added in accordance with the specification. However, due to size limitations in the housing, some problems were encountered in finding components that would fit into the sensor and still filter out RFI and AFI.

Although complete RFI tests were not performed a prototype unit was tested and found to meet the Audio Susceptibility requirements of MIL-I-6181D.

The type of filter incorporated in the unit should enable it to completely conform to MIL-I-6181D.

4.4 ASSEMBLY AND TESTING OF COMPLETE CIRCUIT

After the completion of circuit block development, complete sensor circuits were breadboarded and tested over the specified temperature range. This was done to verify that the circuit block requirements had been accurately defined.

It was necessary to make some revisions in the interface between the ac amplifier and the detector. This involved incorporating transformer coupling and establishing detection levels for the sensor as a whole.

After this modification was incorporated, the circuit performed well over the temperature range. The circuit was then laid out on printed-circuit cards and installed in a prototype sensor. Two prototype sensors were then built and found to operate over the temperature range.

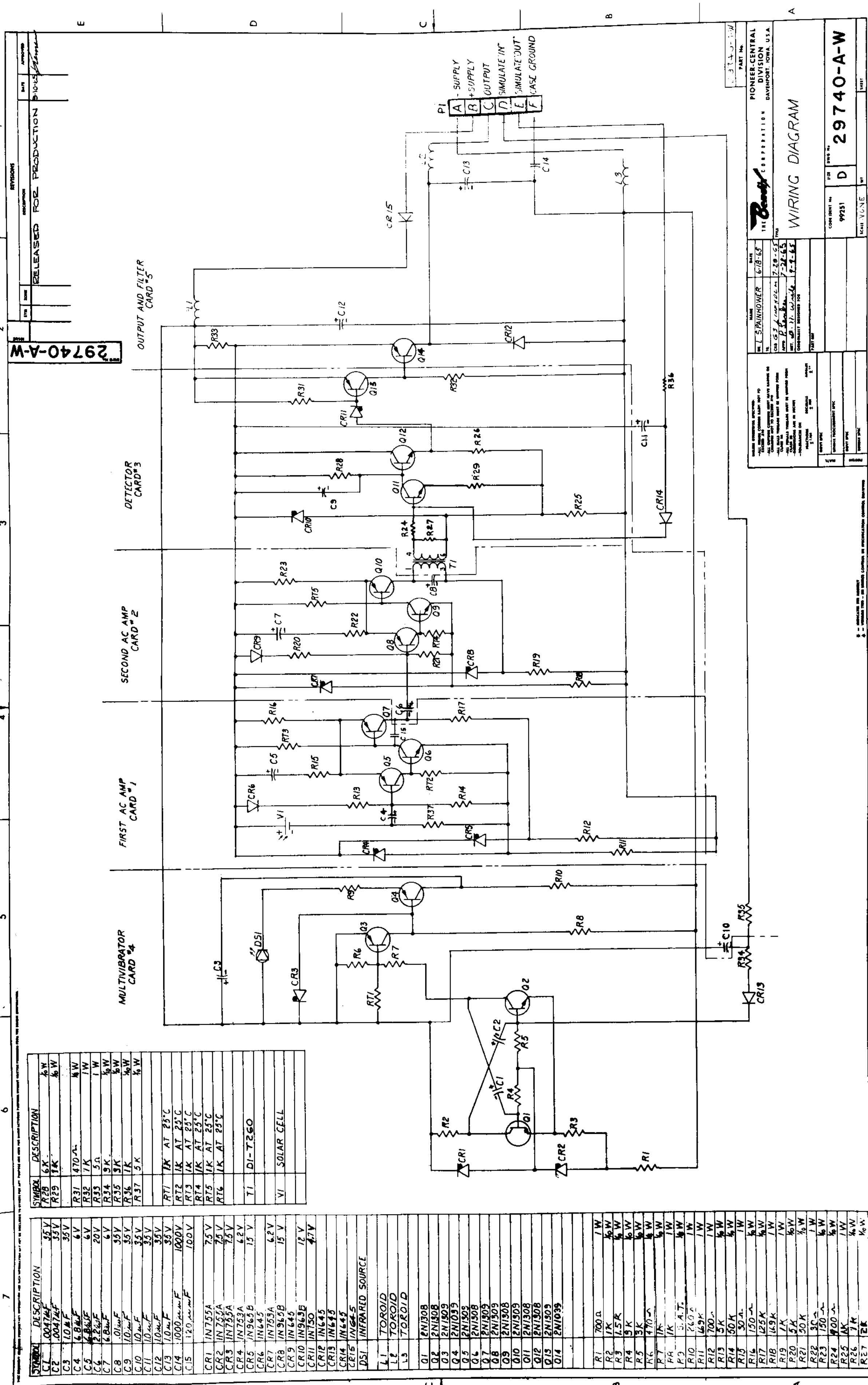

29740-A-W
RELEASED FOR PRODUCTION
OUTPUT AND FILTER CARD "5"
DETECTOR CARD "3"
SECOND AC AMP CARD "2"
FIRST AC AMP CARD "1"
MULTIVIBRATOR CARD "4"
P1
A - SUPPLY
B + SUPPLY
C OUTPUT
D SIMULATE "IN"
E SIMULATE "OUT"
F CASE GROUND
PIONEER-CENTRAL DIVISION DAVENPORT, IOWA U.S.A.
WIRING DIAGRAM
D 29740-A-W
SCALE NONE

Figure 4-8

5.0 PACKAGE DESIGN

5.1 SENSOR ENVELOPE

The sensor outline and basic construction were defined by Specification R-P&VE-PMS-SPEC-4-63 Revision A. Thus, the major packaging effort was directed toward mounting components in a practical arrangement within the space provided. No basic changes were made to the external housing.

The sensor package (see Figure 5-9 for outline drawing) is approximately six inches long and weighs approximately 1 pound. The electronics housing is less than two inches in diameter. The entire housing is fabricated of stainless steel except the prism housing proper which is made of a glass-sealing alloy. This alloy is plated to provide corrosion resistance during use.

5.2 CIRCUIT LAYOUT

As explained earlier, every effort was made during the design phases to minimize the number of components in each circuit because of the fixed amount of volume available for the electronics portion. In spite of this accent on limiting total components, space within the sensor housing was at a premium. For this reason, some of the axial-lead components were mounted vertically on the printed circuit boards and each of the circuit boards contain the maximum number of parts consistent with reasonable circuit layout. The photograph in Figure 5-10 shows the five circuit boards with components for the final sensor circuit shown in Figure 4-8. Starting at the upper left, the boards contain the 1st ac amplifier, 2 ac amplifier, the detector and dc amplifier, the oscillator and LED driver and finally at the lower right, the output stage and filter circuits.

5.3 SENSOR ASSEMBLY

The circuit boards are mounted in the sensor housing in the order mentioned using tubular spacers between circuit boards. Each card-spacer assembly is potted using an aluminum-oxide filled epoxy compound which had previously been developed for this type of service and is compatible with cryogenic temperatures. Figure 5-11 shows a complete set of sensor electronics with the potting compound in place. The photograph in Figure 5-12 was taken just before the card assemblies were slipped into the housing. A stiff circular wave-washer spring is located inside the housing at the prism end and the potted, card-spacer assemblies compress the spring as they are pressed against it until the rear cover is welded in place. Once the end cover is welded in place, the cards form a rigid stack which will withstand the vibration and shock of a stringent environment. A small evacuation hole is located in the rear cover through which the unit is evacuated and backfilled with a helium-nitrogen mixture. The helium leak test is performed within one hour after the back-filling operation. This time is required to permit the evacuation hole to be welded shut. A temporary stopper is kept in the evacuation hole during this period.

THE Bendix CORPORATION

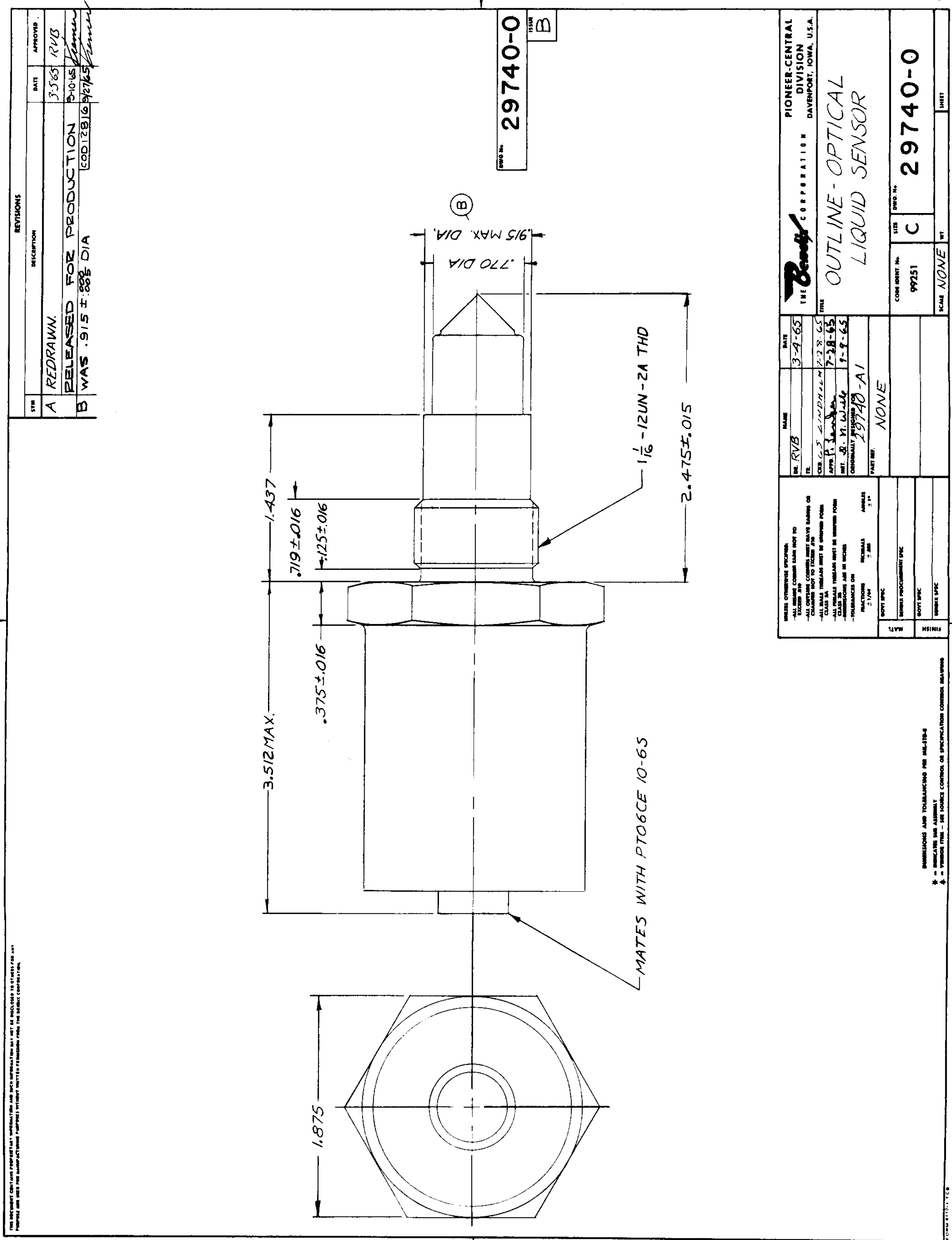


Figure 5-9

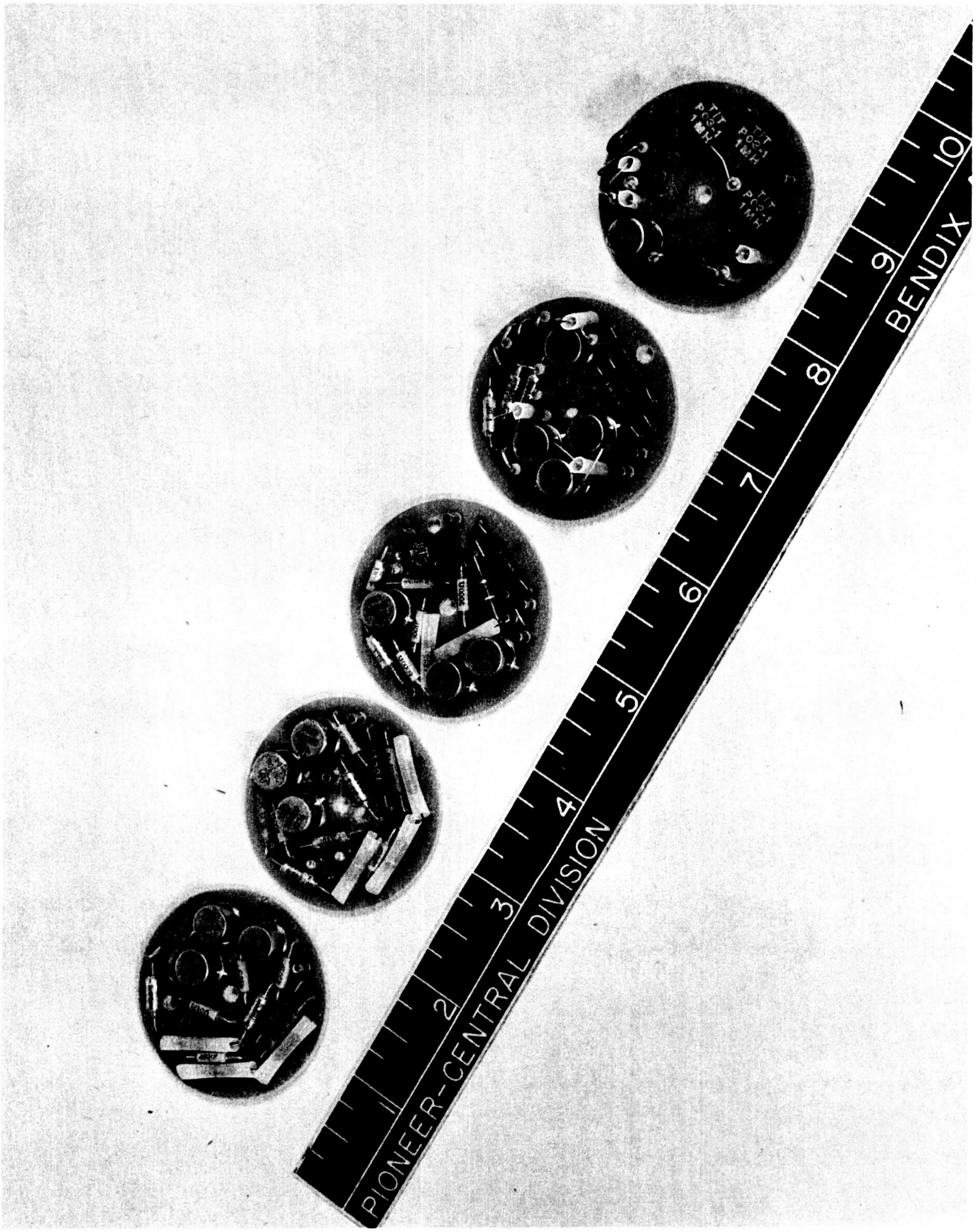


Figure 5-10

One Set of Printed Circuit Cards
Before Potting

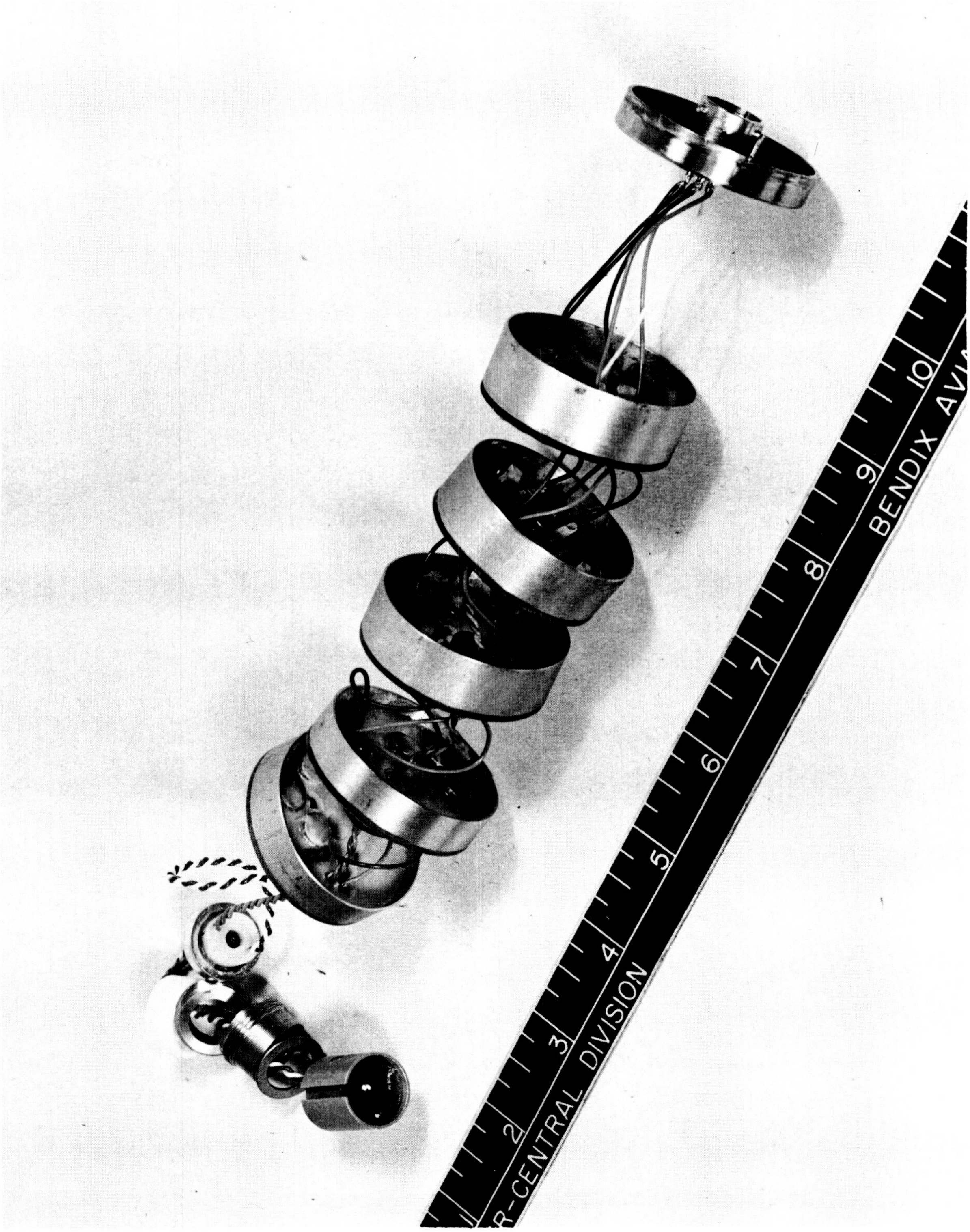


Figure 5-11

One Set of Sensor Cards After Potting

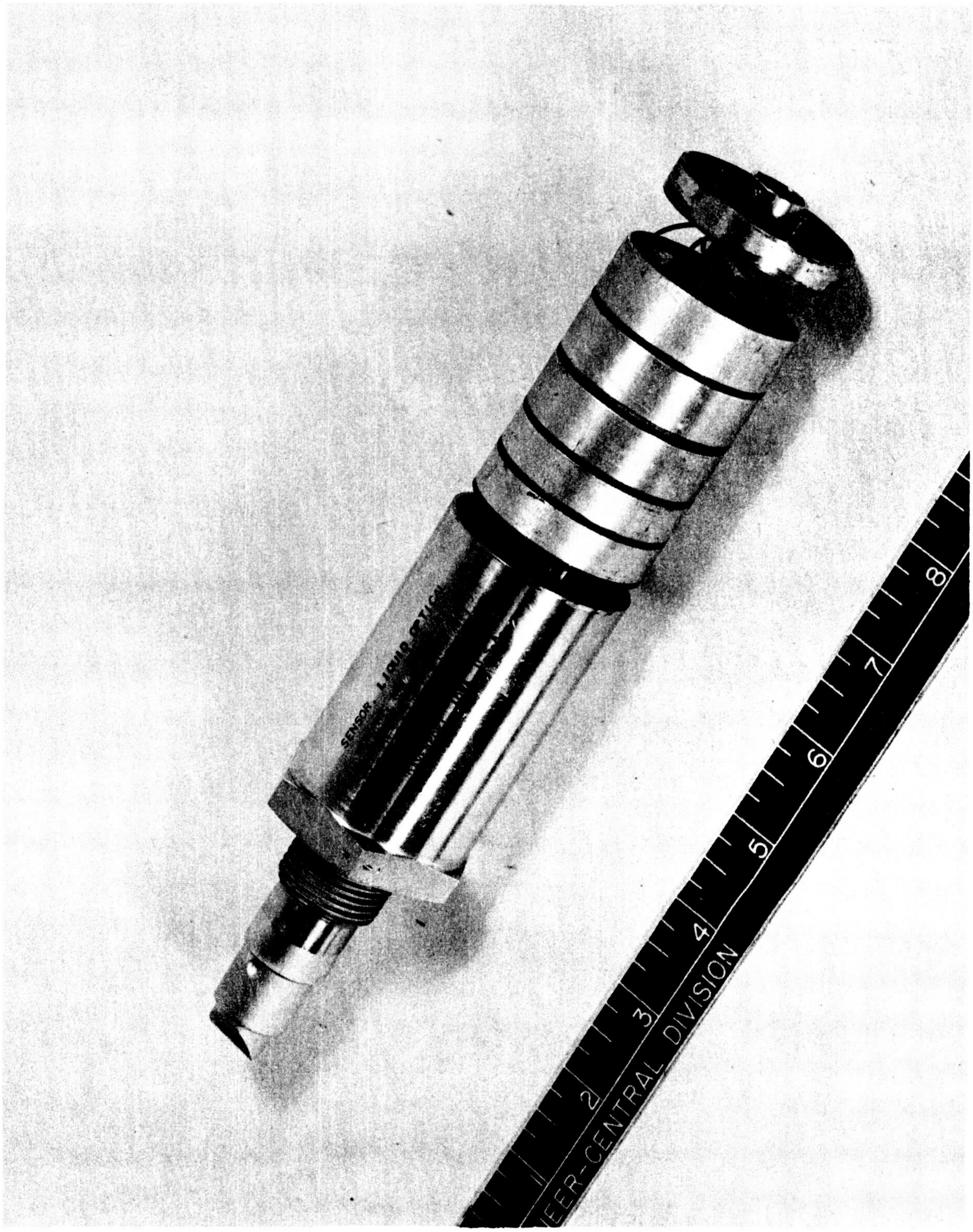


Figure 5-12

Completed Sensor Prior to Final Assembly and Close-up

6.0 TESTING PROGRAM

6.1 TEST SET-UPS

During the course of the program, it was necessary to test components, breadboard circuit blocks and complete sensors over the specified temperature range Conventional instrumentation and test methods were used for all except the tests at liquid hydrogen temperature. Preliminary testing at LN_2 temperature was done by direct immersion of the components and test circuit boards in the liquid.

The explosion hazards attendant with liquid hydrogen testing required a test set-up of the type used in this program.

Most of the circuit and component testing was done in a special test chamber at LH_2 temperature. The fixture consists of a helium-filled chamber which was immersed directly in LH_2. In case of a catastrophic component failure or electrical fault; the possibility of fire and explosion was minimized, since any leakage of the chamber cover seal would cause the expulsion of inert helium rather than allow a seepage of hydrogen into the electrical test area. The use of helium in the chamber also improved heat transfer between the test chamber walls and the components under test. This minimized the soak time required for the components under test to reach LH_2 temperatures. Temperature measurements during testing indicated a difference of less than 2°C between the inside of the thin wall tube and the surrounding LH_2 with the circuit under test de-energized. This temperature was felt to be adequate for preliminary component test.

Test sample performance was monitored with standard test equipment where applicable and with several special test circuits as required. A schematic presentation of the test chamber is shown in Figure 6-13. Figure 6-14 shows a photograph of the actual test set-up.

6.2 COMPONENT TESTING

6.2.1 Transistor Tests

Paragraph 4.2.3 summarizes the results obtained from transistor testing and discussed some of the circuit design aspects of the test results.

It was known from earlier work that current gain in all transistors decreases quite rapidly as cryogenic temperatures are approached. Secondly, germanium transistors exhibit a smaller percentage change in gain than silicon devices at these temperatures. It was also known that silicon units of planar construction will not function even at LN_2 temperature, whereas some transistors of mesa construction perform fairly well. Therefore, only certain types of transistors were investigated for this program.

Using the LH_2 test chamber, preliminary tests were made of the 14 types by comparing the room temperature gain with the gain at LH_2 temperature. A Tektronix curve tracer was used to measure the ac and dc gain at various bias points at both temperatures. All silicon transistors

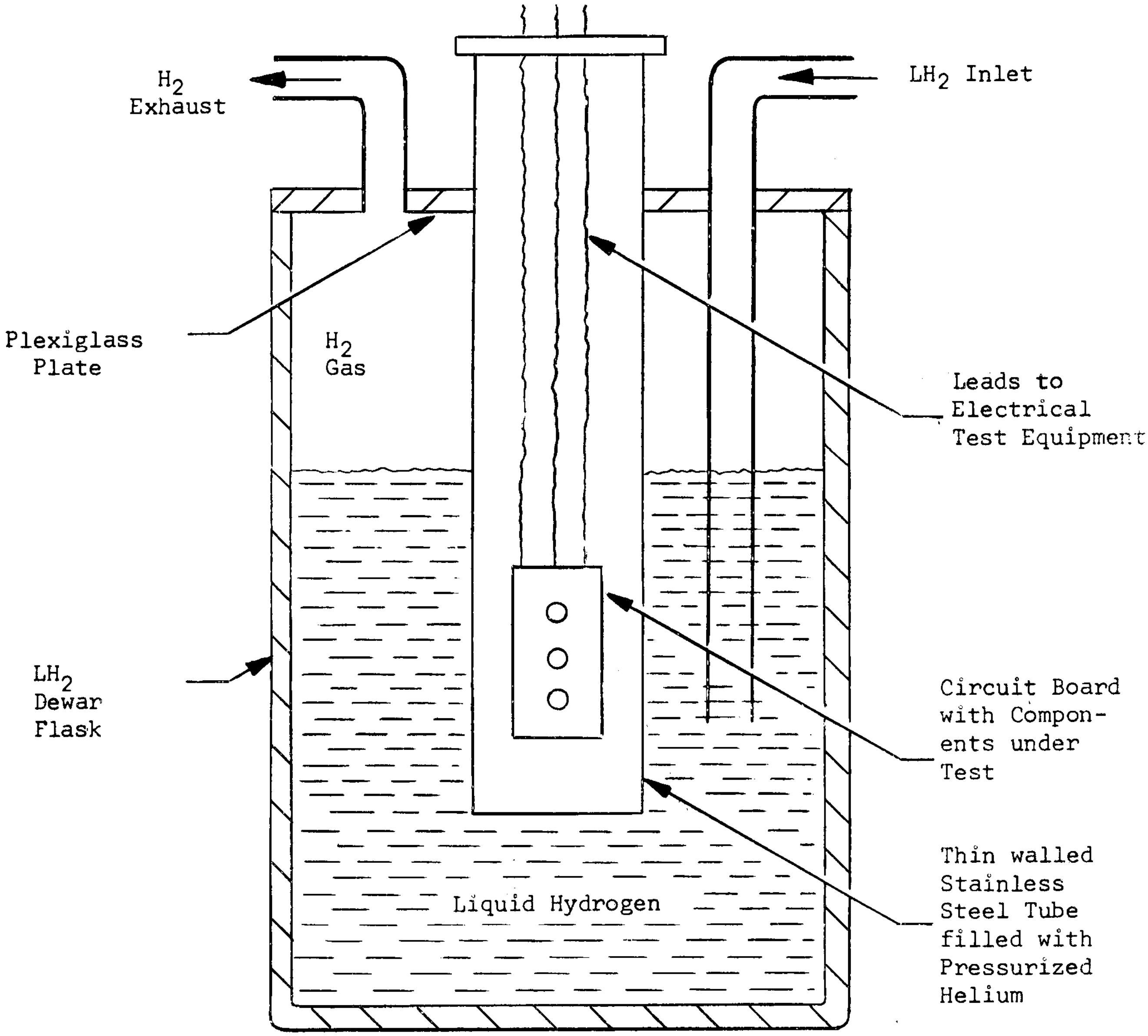


Figure 6-13. Schematic Diagram of LH_2 Test Chamber

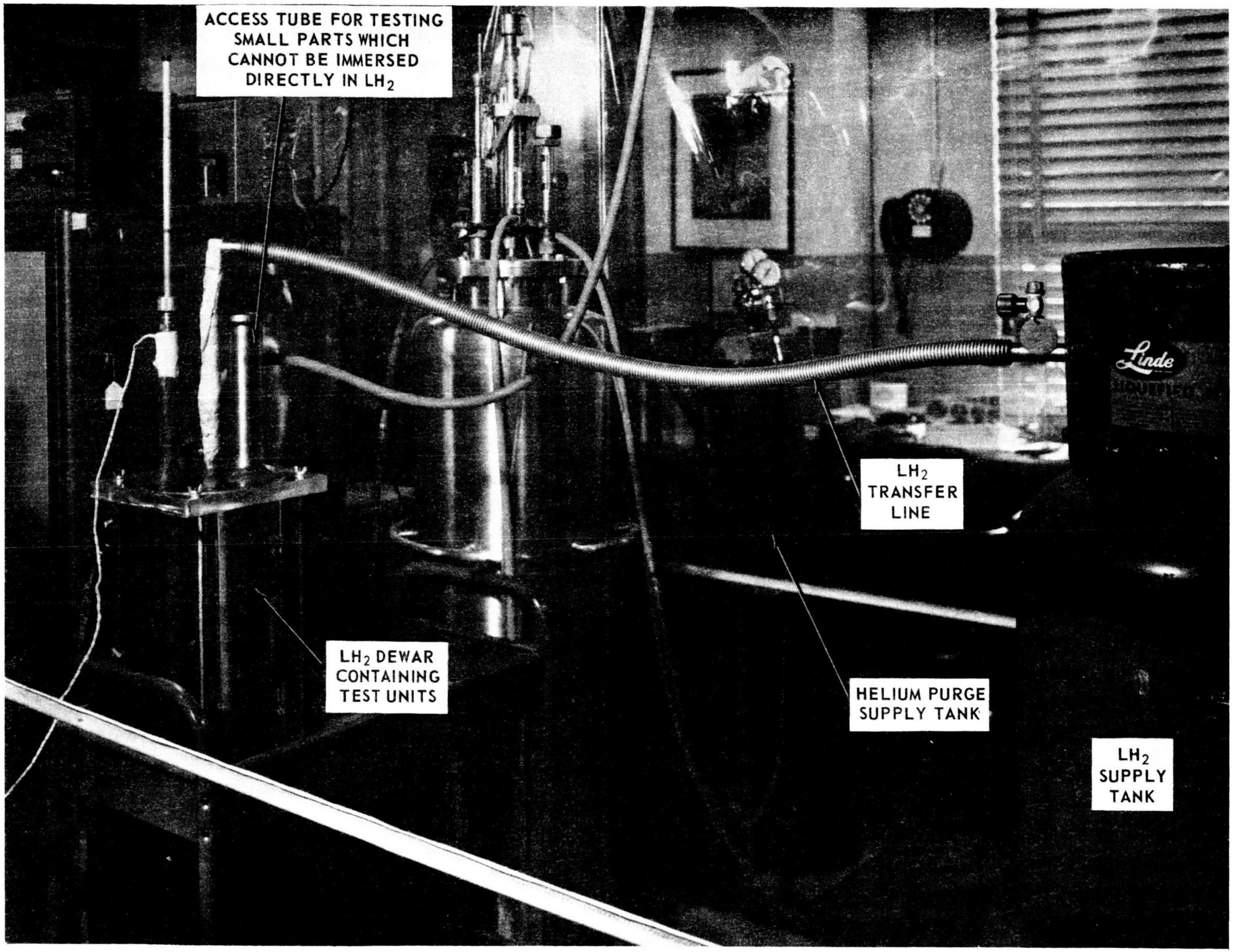


FIGURE 6-14. TEST SET-UP FOR TESTING COMPONENTS IN LIQUID HYDROGEN

failed to operate in liquid hydrogen, including a special device designed to operate at liquid nitrogen temperature. Two types of silicon field-effect transistors also failed at -255°C. However, seven of the germanium devices did retain a usable percentage of their nominal gain. The average ac (h_{fe}) and dc (h_{FE}) gains of these transistors are listed in Table II. As indicated in the table, five of the seven germanium transistor types were selected for further tests at LH_2 temperature in larger quantities. With the exception of the 2N1039, which was the only power transistor among the seven, the transistors selected were switching devices. The 2N1039 had been used in liquid nitrogen applications previously at Pioneer-Central. The curve tracer was not used for the additional tests because capacitive coupling between the many component lead wires caused erroneous readings. Capacitance effects of shielded cables introduced extraneous load capacitance which also affected the measurements. Therefore, dc measurement of current gain was used in these tests. Using the dc value was considered to be conservative, since the ac values were always higher when both ac and dc gain values were measured in earlier tests.

The characteristic curves at room and LH_2 temperatures for the transistors tested are reproduced in Appendix I. These curves show gain and emitter-to-base voltage characteristics.

Transistor data was examined on the basis of gain, emitter-to-base voltage characteristics, and leakage characteristics. Of all the transistors tested, three were chosen for use in this project. These were the 2N1308, 2N1309, and 2N1039, all manufactured by Texas Instruments. The 2N1308 and 2N1309 devices were chosen for all functions where power demands are small. The 2N1039 is a 20-watt device and was chosen for use in the output stage and for pulsing the LED.

Data taken on 25-30 samples each of the three types of transistors indicated the average minimum gain of the 2N1308 and 2N1309 to be 7-10 while the gain of the 2N1039 went as low as 2-3, depending upon current level. Thus, the minimum gains for design purposes were 5 for the 2N1308 and 2N1309 and 2 for the 2N1039.

See Appendix I for photos of curve-tracer tests.

6.2.2 Diode Testing

6.2.2.1 Zener and Forward Silicon Diodes

Both zener diodes and silicon forward diodes were tested at LH_2 as well as room temperatures. The diodes were mounted on test boards and immersed in the helium-filled chamber of the test fixture described earlier. Characteristics were determined by using a curve tracer.

The following silicon diodes were tested: 17 samples of 1N645, 3 samples of 1N750A, 5 samples of 1N755A, 8 samples of 1N963, 12 samples of 1N965.

In general, it was found that forward diodes increased their forward voltage drop approximately 2 to 1 at LH_2 temperatures as compared to room temperature values.

Zener diodes were found to have a positive temperature coefficient which is an extension of the coefficient found in more common temperature ranges. Zener diodes with characteristic voltages in the 5 to 6 volt ranges showed only minor changes with temperature. Units having higher nominal voltage ratings were found to show greater percentage reduction in operating voltage at LH_2 temperatures.

It was also found that, in general, leakage characteristics of all diodes were reduced at LH_2 temperature.

Curve tracer photographs of the characteristics of several diodes are included in Appendix I along with photos of transistor curves.

6.2.2.2 Light Emitting Diodes

Three types of light emitting diodes were considered as light sources for this sensor - the TI SNX100, Microstate MS700, & Hewlett-Packard's hps-4104. All are Gallium-Arsenide forward biased diodes. Samples of each were tested with a standard solar cell at room temperature for comparison. They were then connected into a multivibrator-driven circuit with a prism and solar cell assembly connected to a two-stage ac amplifier. The output of the amplifier with all three diodes was compared at +60°C, room temperature and at LN_2 temperature. This data is shown in Table III.

DIODE	TEMPERATURE	TEST CELL OUTPUT P-P VOLTS	MINIMUM OUTPUT	MAXIMUM CHANGE LN_2 TO + 60°C
Microstate MS 700	Room	2		
	LN_2	2.5	1.3	1.2
	60°C	1.3		
H-P Associates hpa 4104	Room	2.3		
	LN_2	6.4	1.4	4.6
	60°C	1.4		
Texas Instruments SNX100	Room	1.5		
	LN_2	2.0	0.7	1.3
	60°C	0.7		

TABLE III. LED Temperature Test Data

Since each LED was tested with a standard solar cell, and no other components were exposed to the temperature variations, the output variations represented characteristics of the LED. The H-P and the Microstate devices had approximately the same minimum outputs, but the Microstate unit showed the best stability over the temperature range. In light of these comparisons, the Microstate LED was chosen for use in the 29740 optical liquid sensor.

6.2.3 Solar Cell Testing

Past experience with solar cells of the dual-section shingle construction (each section was .5 cm x .5 cm) had shown occasional failures due to mechanical cell damage as a result of differential thermal expansion coefficients. The problem was usually due to deterioration or failure of the lapped electrical connection between the two cell sections. This joint was loaded in shear since the fiber-glass epoxy base laminate has a considerably greater coefficient of expansion than the bulk silicon of the cell sections.

An attempt was made to solve this problem by designing a solar cell assembly in which the two sections were mounted individually to separate pads of a small printed-circuit card. However it was still necessary to connect electrically to the positive top conducting surfaces of the cell sections with leads. Sufficient difficulties were encountered in maintaining positive electrical connection that this configuration was discarded.

Solar cells of a single large section (.5 cm x 1 cm) were then tested and found to produce good consistent test results.

The lower characteristic impedance of the single section cell matches the amplifier input impedance quite well. Therefore this type solar cell was incorporated in the 29740-A1 sensor.

Since all solar cells tested performed adequately electrically, no comparison of electrical performance is included in this report. Evaluation was based strictly on mechanical integrity of the cell and holder assembly when cycled over the temperature range.

6.2.4 Capacitor Tests

In previous cryogenic optical sensors, both solid tantalum and silver-mica type capacitors were used with good results. For this reason, only these proven types were tested at LH_2 temperature at first. Since the components showed only slight temporary change at liquid hydrogen temperature, it was decided that their operating temperature range could be extended from LN_2 to LH_2 for use in the 29740-A1 sensor.

6.2.5 Resistor Testing

Three types of resistors, wire-wound, metal-film, and composition resistors, were tested at LH_2 temperatures. The wirewound and metal-film resistors showed a change in resistance on the order of 1%. Composition resistors were found to increase in value considerably as cryogenic temperatures were approached. The percentage change was greatest for high nominal values, approximating 200% of room temperature value at LH_2 temperatures.

As a result of these tests, wirewound and metal-film resistors were selected for use in the unit where constant values were required. Composition resistors were considered for use as temperature compensation elements.

Several failures of the 1/10 watt IRC metal-film resistors and an occasional failure of the wirewound resistors during build-up and unit test indicated that there was a reliability problem with these parts when used at cryogenic temperatures.

As a result of this problem, a test program on this item was initiated. One hundred IRC 1/10 watt metal-film resistors were tested under conditions simulating conditions in the sensor. Fifty resistors were mounted on end and the other 50 were mounted horizontally on boards. All were cycled twice in LN_2, then 10 times in LH_2. Each cycle was from room temperature to LH_2 temperature for 30 minutes, then back to room temperature for 30 minutes. A quick resistance check was made as the test boards were removed from the test chamber to determine any open resistors while boards were still cold. The actual resistance was measured with a Wheatstone Bridge at room temperature after each cycle.

The test was designed to determine the effect of the potting on the failure of the resistors. Therefore, every other resistor was sleeved with teflon tubing to prevent adhesion to the potting material.

Also, twenty-four Dale 1 watt wirewound resistors were mounted horizontally on a test board and tested in the same manner as the metal film units. The results of the testing are summarized in Table IV.

METAL FILM - NUMBER OF FAILURES				
	UNPOTTED		POTTED	
	SLEEVED	UNSLEEVED	SLEEVED	UNSLEEVED
VERTICAL MOUNTING	One	One	One	One
HORIZONTAL MOUNTING	None	None	Three	None
WIREWOUND - NUMBER OF FAILURES				
NONE				

TABLE IV. Resistor Test Results

A tabulation of the resistance measurements taken after the various temperature cycles is given in Appendix II of this report.

The general problem with the resistor failures, resulted in delays during the latter part of the program while quantities of the resistors were being tested. An alternate source for the 1/10-watt metal-film resistors has now been established. The reliability of the resistors incorporated in the three sensors delivered is not as high as desired. However, because of the extensive testing done on the sensors it is anticipated that they will remain operational during the remainder of the test program.

6.3 BREADBOARD CIRCUIT TESTING

During the development of the circuit blocks described in paragraph 4.3, the test circuits were assembled on printed circuit cards which were mounted in the LH_2 test chamber. Test leads were brought off the test circuits at critical points for monitoring circuit operation at LH_2 temperatures. This permitted careful study and analysis of the circuit under test and led to development of the circuit blocks which are incorporated in the final unit.

After completion of the circuit block development, complete sensor circuits were breadboarded and tested similarly to verify capabilities of the complete circuit.

6.4 PROTOTYPE TESTING

After completion of breadboard circuit tests, two prototype units were constructed and tested by direct immersion in LH_2 in the test fixture. The units were moved in and out of liquid while supply voltage was varied to determine high and low operating voltage limits.

The units were immersed, de-energized and allowed to cool down internally. They were then energized to verify operation without warm-up time.

6.5 TESTING OF FINAL UNITS

6.5.1 Preliminary Tests of Final Units

During these tests, the circuit boards were assembled into the sensor housing, but the rear cover was not welded into place. The sensor was then tested in and out of liquid hydrogen while the voltage and the current were measured at the maximum and minimum values over which proper operation was maintained.

The three sensors were subjected to approximately five thermal cycles each to determine operating characteristics before close-up. During this series of tests a total of five one-tenth watt resistors and two transformers developed open circuits.

The recurrence of metal film resistor failures resulted in the initiation of the resistor test program described in paragraph 6.2.5 of this report. The two transformer failures were investigated and attributed to differential expansion characteristics of the materials used in the transformers. A cooperative program was established between Pioneer-Central and the transformer supplier to develop a configuration which will not be subject to this type of failure. When the partially-assembled sensors showed satisfactory operation during a minimum of five high and low temerature cycles, the three units to be delivered were sealed and acceptance testing started.

6.5.2 Final Acceptance Testing

Using the test set-up, Figure 6-14, three complete level sensors were tested in accordance with Pioneer-Central Engineering Specification 602A including immersion in liquid hydrogen. All three units passed the tests and were delivered to NASA. The data taken during these tests, which were witnessed by both Pioneer-Central and NASA quality control representatives, is reproduced as Appendix III of this report.

7.0 SUMMARY

Most of the engineering effort required for the development of a satisfactory one-piece optical liquid sensor for operation in LH_2 was directed towards accomplishing the following tasks: (1) the development and testing of electronic circuitry capable of operation at normal and LH_2 temperatures, (2) the testing of electronic components to determine their physical and electrical characteristics at LH_2 temperatures, and (3) the development of satisfactory packaging techniques for the extreme environment specified.

All development goals were achieved with the exception of the electrical response time requirements. Component reliability problems were solved for the LH_2 environment. For example, the one-tenth watt metal-film resistors originally selected revealed periodic failures during the build-up and test phase of the program. Also several of these resistors failed in final units and had to be replaced. Alternate resistors have been tested at cryogenic temperatures in other Pioneer-Central programs to establish adequate sources for parts for this type application. Failures were also experienced in a miniature transformer after repeated thermal cycling. These failures were due to differential thermal expansion characteristics in the transformer materials. A cooperative program established between Bendix and the transformer supplier resulted in a transformer design which is not subject to this type of failure.

Sources now exist for all parts required in the LH_2 sensor. Therefore, a production program for liquid-level hydrogen sensors is presently feasible with the understanding that vendor certification for component operation at LH_2 temperatures will need to be obtained, or provision made for conducting sufficient tests to assure the reliability of each component.

Initially, it was anticipated that the design goal of 1 millisecond response could be achieved through use of an ac excited light source. A 10 kc excitation frequency was used to allow sufficient integration time in the RC-diode detector. However, the switching circuits had a longer response time than was anticipated, and a system response time of 4 to 6 milliseconds resulted (depending on whether the sensor is tested in going from "in liquid" to "out of liquid" or vice versa). The reason for the slower response time was not completely identified. However, it is believed that most of the delay is caused by the RC time constant of the test circuit filter networks and the LC time constant in the output lead. This problem was discussed during an informal program review, and it was agreed that the longer response time was not a serious limitation, and was of lesser importance than such considerations as the repeatability of response time under a given set of conditions, and the reliability of operation under LH_2 conditions. Also, it is important to note that the time required for liquids to move on or off the sensing area of the sensor is on the order of 10 milliseconds, and depends on the fluid dynamics in the sensing area. However, it is believed that the electrical response time of the units can be reduced to the 1 millisecond design goal by further work.

In summary, the LH_2 sensor development program indicates that a one-piece LH_2 point sensor can now be produced. The major problems associated with the operation of the electronic circuitry at cryogenic temperatures have been solved, and point sensors can be produced which have an adequate reliability when operated in the LH_2 environment.

8.0 RECOMMENDATIONS

The work done in this program has resulted in development of a LH_2 point sensor which is operational under the environmental conditions specified. However, in the following general areas additional effort could result in an improved design: (1) power drain should be reduced, (2) size and weight should be reduced, (3) complexity should be reduced, (4) response time should be reduced, and (5) new components should be investigated for applicability to LH_2 operation.

Since the design freeze to permit delivery of the three units, much has been learned about cryogenic circuitry. This is the result of work done in this program as well as in other programs at Pioneer-Central. For example, field-effect transistors with good operating characteristics at cryogenic temperatures have recently become available and are being investigated. Due to their extremely low leakage at all operating temperatures and their high power gain, these devices are ideally suited for this type of application. Their use should permit reduction in the number of parts in the ac amplifier and detector sections of this type sensor.

Work already completed has resulted in the following developments. A simplified circuit reducing the number of components from 22 to 10, has been developed for driving the light emitting diode. As improved methods for providing the detection and integration functions are developed, it will be possible to adapt this simplified circuit for liquid-level sensor application at hydrogen temperatures without sacrifice of response time. Also, it should be possible to reduce time delays caused by the filter networks in the test circuits and the output circuit. A new output driver circuit with fewer parts and improved operating characteristic recently been developed.

In Section 4, Circuit Design, it was indicated that a light-emitting diode (LED) was used as the light source in this unit because no practical incandescent lamps exist which will meet the 50 g vibration levels specified. The low light output level of the LED requires ac excitation, detection of low-level signals from the solar cell, and high-gain amplification, all of which contribute to the complexity of the circuits. The development of an incandescent light source which would tolerate 50 g vibration levels would greatly simplify the circuit design. It is recommended that a program be undertaken to develop such a light source. A filament operated at a low-color temperature can be used effectively with silicon solar cells, and thus, the design advantage that lamp operating efficiency can be lower than normal for visible illumination. It is estimated that the use of such a lamp would decrease the number of electrical components required by approximately 50%, which would result in a significant cost and physical size reduction.

The work done in this program has considerably increased the understanding of operating circuitry at cryogenic temperatures. This opens up numerous possibilities in many areas of cryogenic instrumentation, since electrical cable problems can often be greatly reduced or eliminated with proper system design. Pioneer-Central is investigating this larger area along with further application to liquid sensing.

APPENDIX I

CURVE TRACER PHOTOGRAPHS OF SEMICONDUCTOR COMPONENTS DURING TEMPERATURE TESTS

The photographs on the following pages were taken from the display of a Type 575 Tektronix curve tracer under test conditions described in paragraph 6.2.1 and 6.2.2 of this report. Since the oscilloscope camera uses a mirror, the graph is reversed from the normal curve tracer display.

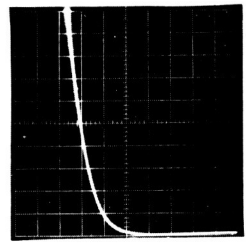
These photographs are not intended to be all inclusive but are presented to illustrate the techniques used in diode and transistor testing. The results included here show comparative performance of different devices as well as help establish desirable operating conditions for the devices.

Diode current as a function of applied voltage for 1N645. Scales are as shown.

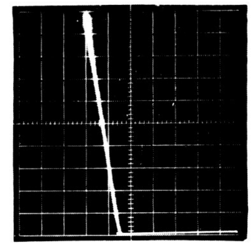
Vert. - 1 MA/Div.
Horiz. - .1V/Div.@Room,
.2V/Div.@ LH_2

Diode #13

Room

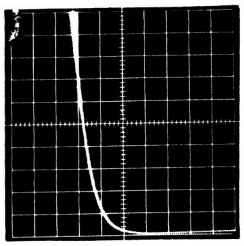


LH_2

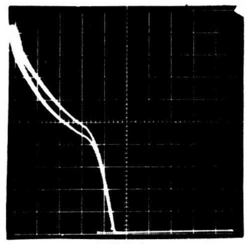


Diode #14

Room



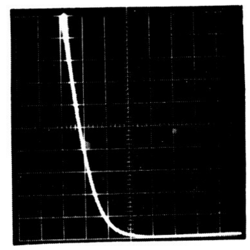
LH_2



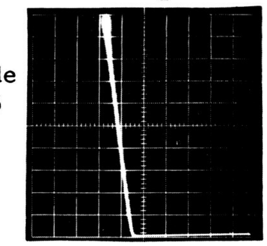
Example of Anomaly

Diode #15

Room

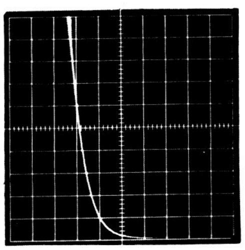


LH_2

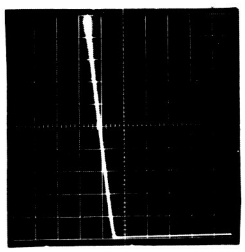


Diode #16

Room

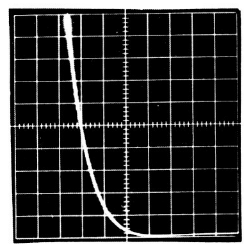


LH_2

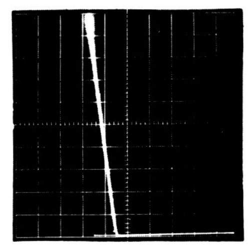


Diode #17

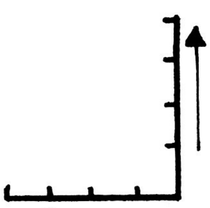
Room



LH_2



Diode current as a function of applied voltage for 1N750A. Scales as shown.

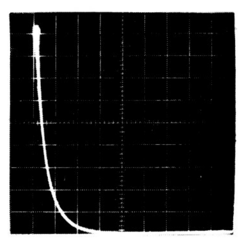


Current
2 milliamps
per division

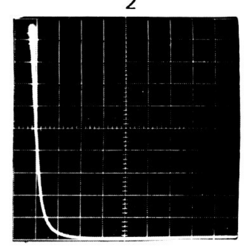
Voltage
0.5 volts per division

Diode # 1

Room

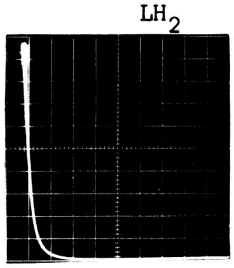


LH_2



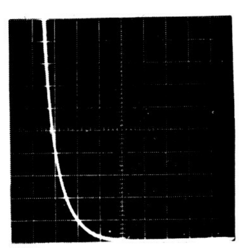
Diode # 2

LH_2

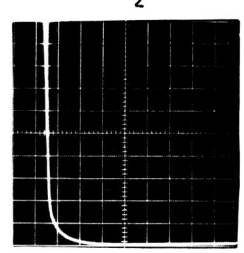


Diode # 3

Room

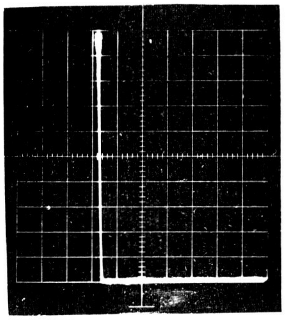


LH_2

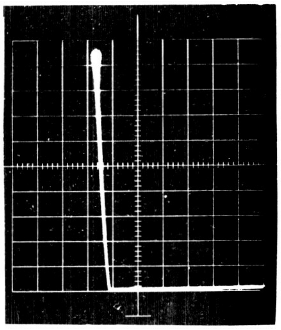


IN755A
Horizontal: 1 V/cm
Vertical: 2 ma/cm

Diode #4

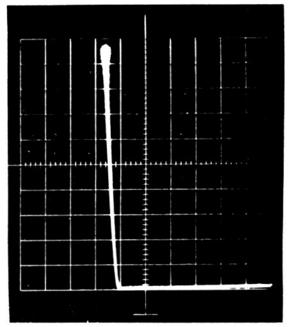


Room



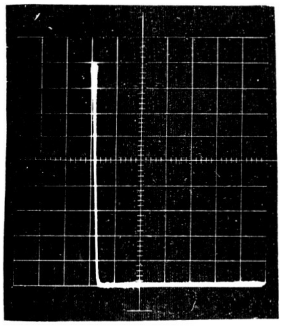
LH_2

Diode #5

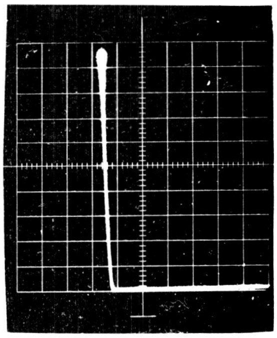


LH_2

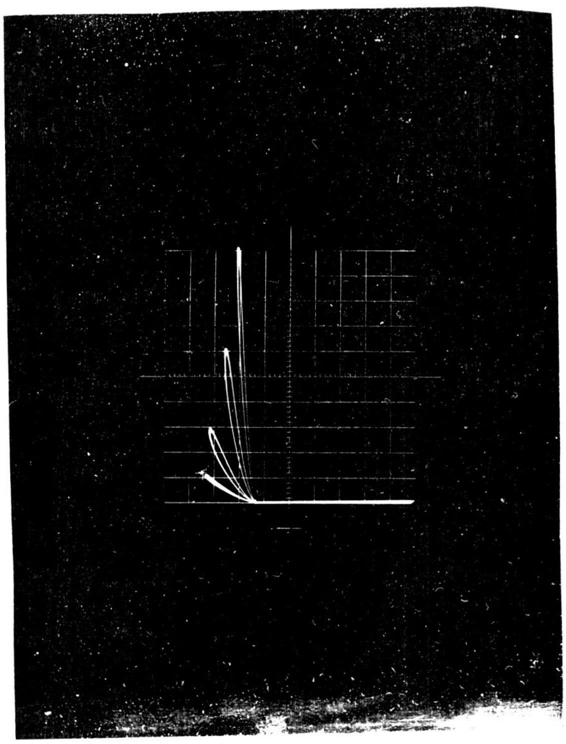
Diode #6



Room



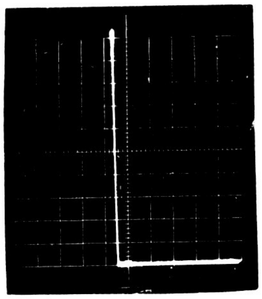
LH_2



IN755A
1 volt,1 ma/cm

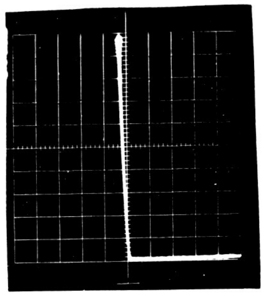
This illustrates the effect of heating in the diode. At low current levels the zener knee is very soft. As the current increases, the diode heat increases and its knee sharpens.

IN963
Horizontal: 2 v/cm
Vertical: 1 ma/cm



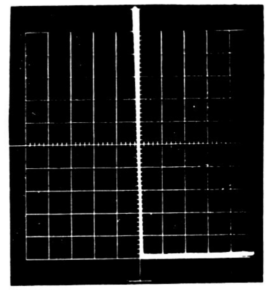
Room

Diode
#7

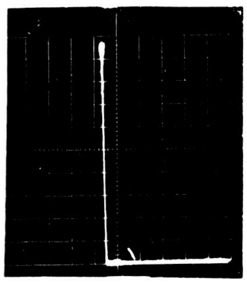


LH_2

Diode
#8

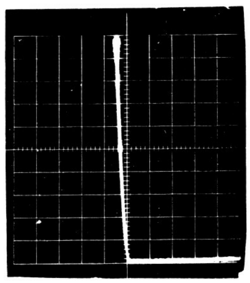


LH_2



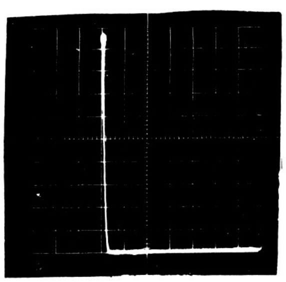
Room

Diode
#9



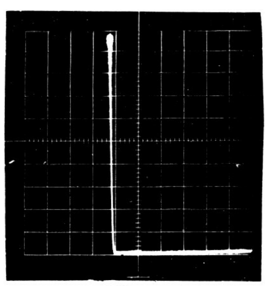
LH_2

IN965
Horizontal: 2 v/cm
Vertical: 1 ma/cm



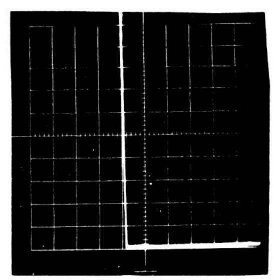
Room

Diode
#10

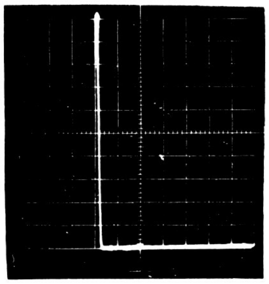


LH_2

Diode
#11

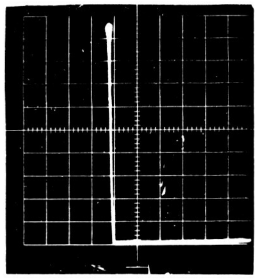


LH_2



Room

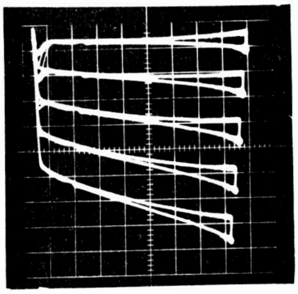
Diode
#12



LH_2

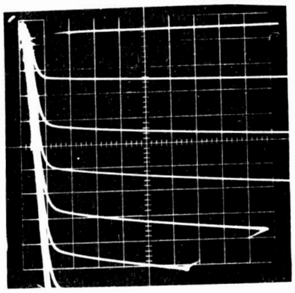
GA-733

#1



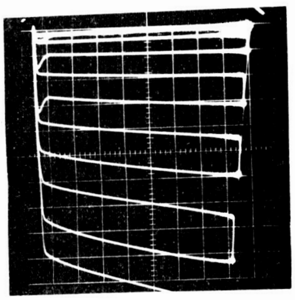
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
h_{fe} = 80
h_{FE} = 69

Room



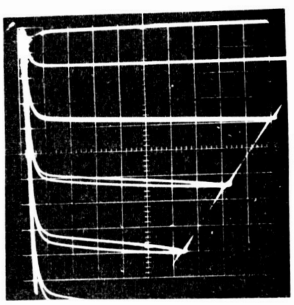
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 76
h_{FE} = 64

Room



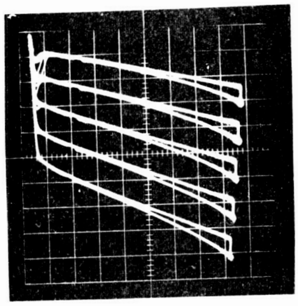
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 5.6
h_{FE} = 3.2

LH_2



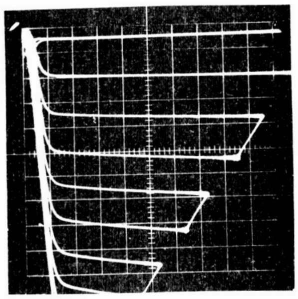
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 10
h_{FE} = 3.1

#3



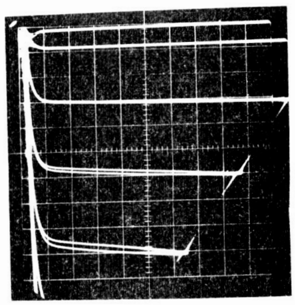
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
h_{fe} = 70
h_{FE} = 75

Room



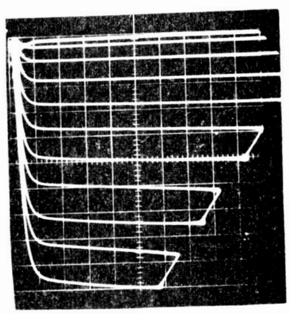
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 56
h_{FE} = 52

Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 5
h_{FE} = 2.85

LH_2

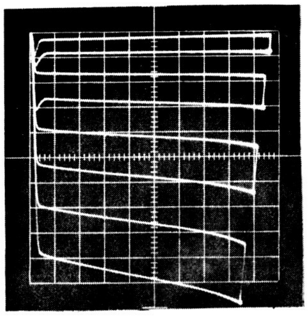


Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 11
h_{FE} = 4

LH_2

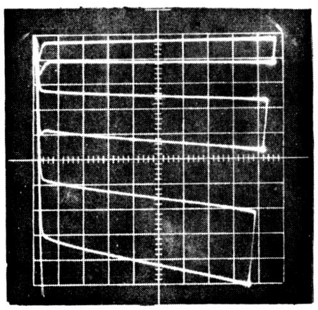
2N711B

Three 2N711B Transistors



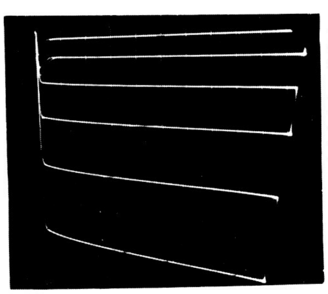
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.01 ma/step
h_{fe} = 32
h_{FE} = 19

#1 Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.005 ma/step
h_{fe} = 92
h_{FE} = 53

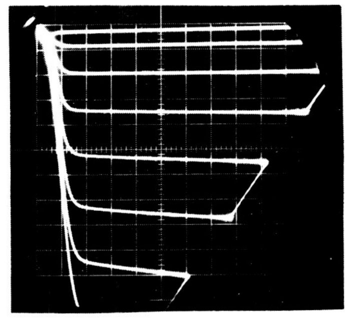
#2 Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.02 ma/step
h_{fe} = 25
h_{FE} = 15.5

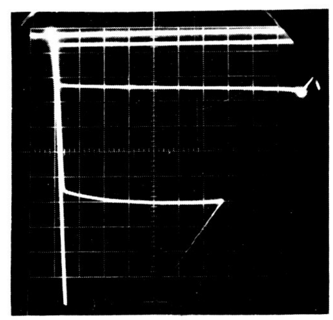
#3 Room

2N711B
Temperature Tests



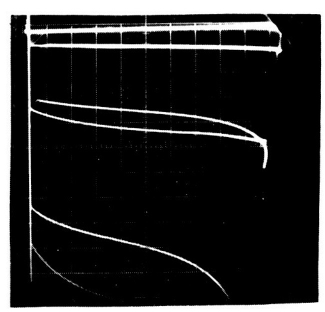
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 76
h_{FE} = 43.2

#1 Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 46
h_{FE} = 17.5

#2 LH_2



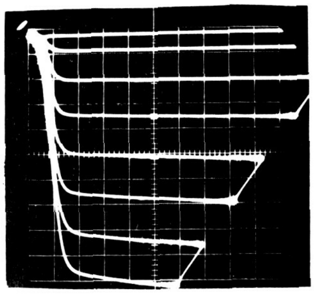
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.1 ma/step
h_{fe} = 15
h_{FE} = 16

#3 LH_2

THE Bendix CORPORATION

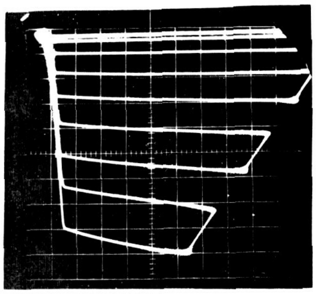
2N711B

#2



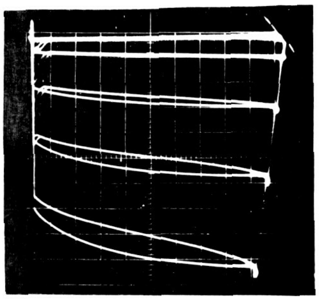
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.02 ma/step
h_{fe} = 160
h_{FE} = 101

Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 14
h_{FE} = 7.8

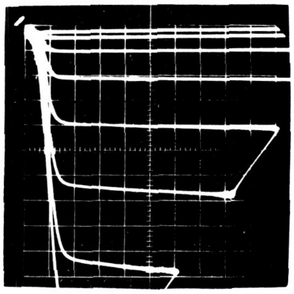
LH_2



Horizontal: 1 v/cm
Vertical: 2 ma/cm
Base: 0.1 ma/step
h_{fe} = 45
h_{FE} = 25

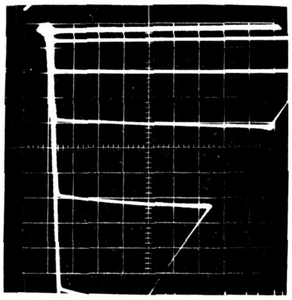
LH_2

#3



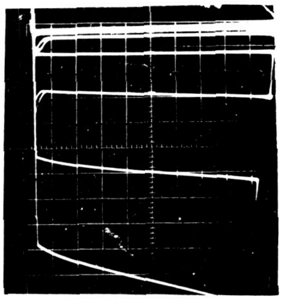
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 104
h_{FE} = 44

Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 13.2
h_{FE} = 5.8

LH_2

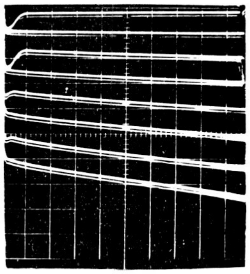


Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 31
h_{FE} = 10

LH_2

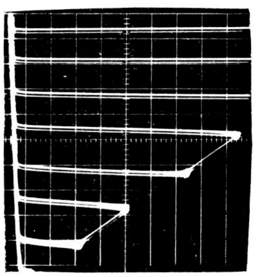
2N388A

#3



LH$_2$

Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 4.4
h_{FE} = 3.7



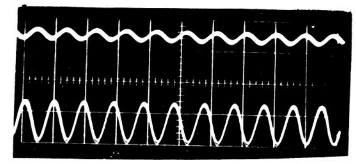
LH$_2$

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 6.4
h_{FE} = 4.6

2N388A #'s 1 & 2 failed at liquid hydrogen temperatures.

2N3277

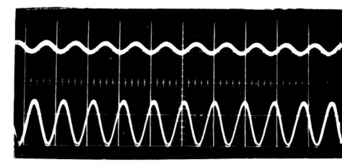
#1



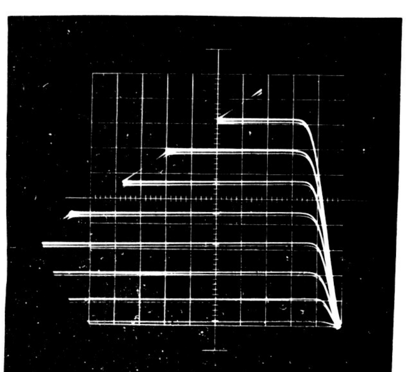
Upper Trace (Input) 0.5 v/cm
Lower Trace (Output) 0.5 v/cm

Both units failed to operate at LH$_2$ temperatures.

#2



2N2985

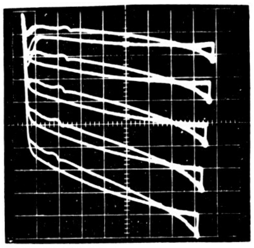


Room Temperature
Horizontal: 0.2 v/cm
Vertical: 10 ma/cm
Base: 0.2 ma/step

This transistor failed to operate at liquid hydrogen temperatures.

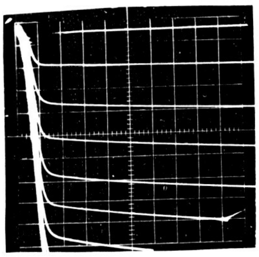
GA-733

#4



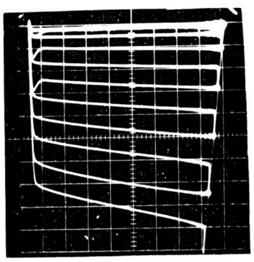
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.001 ma/step
h_{fe} = 185
h_{FE} = 160

Room



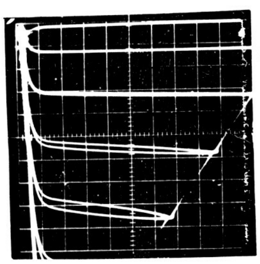
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.02 ma/step
h_{fe} = 170
h_{FE} = 135

Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 4
h_{FE} = 2.5

LH_2

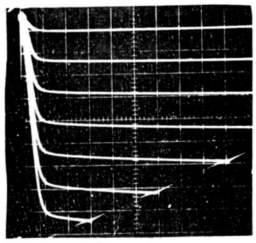


Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 10
h_{FE} = 3.8

LH_2

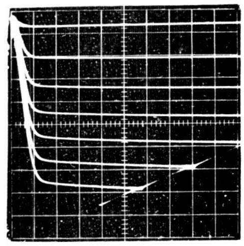
2N1039

#20



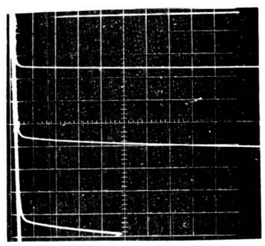
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 60
h_{FE} = 53

Room



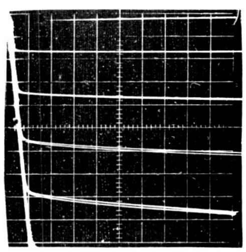
Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 0.5 ma/step
h_{fe} = 45
h_{FE} = 45

Room



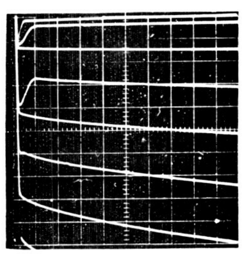
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 2 ma/step
h_{fe} = 3.2
h_{FE} = 2.0

LH_2



Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 5 ma/step
h_{fe} = 9
h_{FE} = 5.9

LH_2

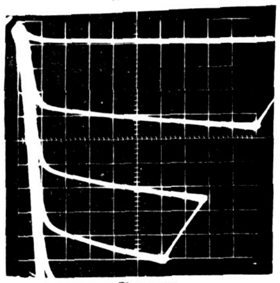


Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.2 ma/step
h_{fe} = 2
h_{FE} = 1.15

LH_2

2N652A

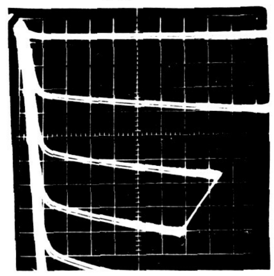
#2



Room

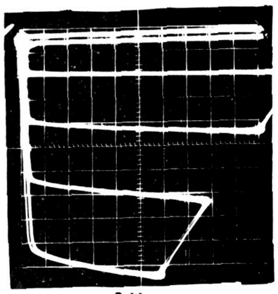
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 120
h_{FE} = 94.6

#3



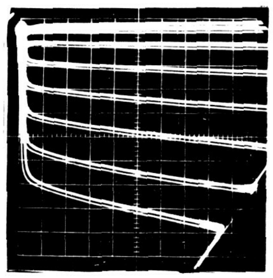
Room

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 104
h_{FE} = 83



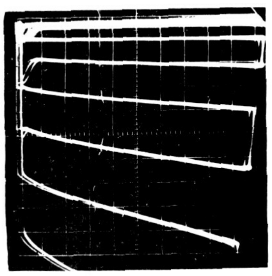
LH_2

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 11.2
h_{FE} = 7.0



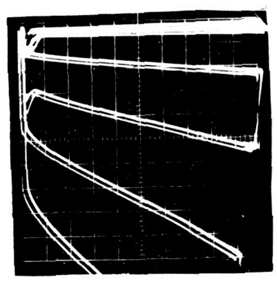
LH_2

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.5 ma/step
h_{fe} = 6.8
h_{FE} = 3.9



LH_2

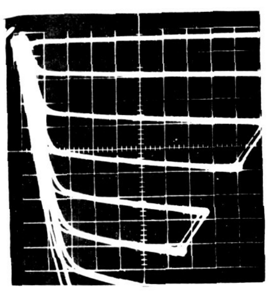
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.1 ma/step
h_{fe} = 4.4
h_{FE} = 2.8



LH_2

Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.1 ma/step
h_{fe} = 6.6
h_{FE} = 3.7

#1



Room

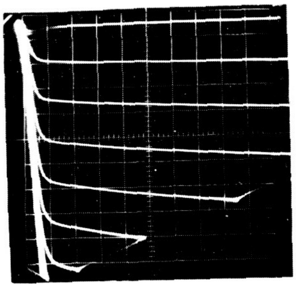
Horizontal: 2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 18
h_{FE} = 18

This unit failed to operate
at liquid hydrogen temperatures.

2N404A

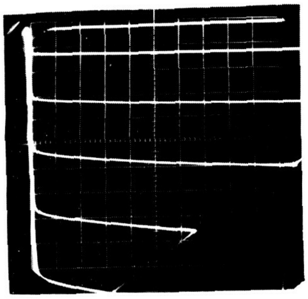
2N404A

Transistor #1



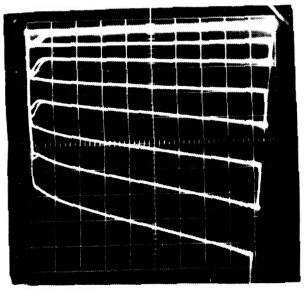
Horizontal: 0.2v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 72
h_{FE} = 55

Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 24
h_{FE} = 14.5

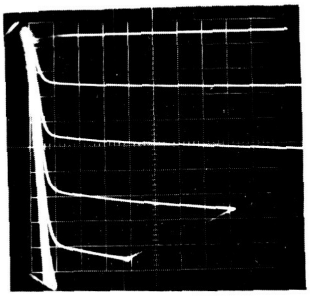
LH_2



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.02 ma/step
h_{fe} = 14
h_{FE} = 7.4

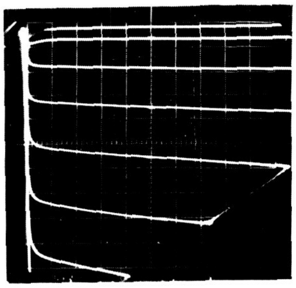
LH_2

Transistor #3



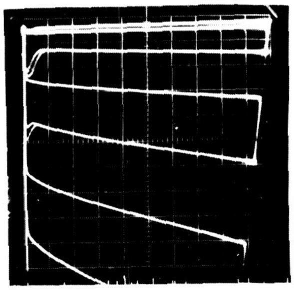
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 96
h_{FE} + 66.6

Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 20
h_{FE} = 11.2

LH_2

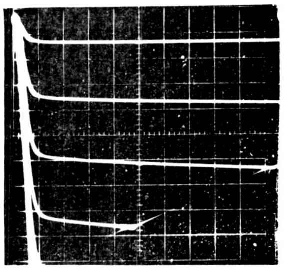


Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 10
h_{FE} = 4

LH_2

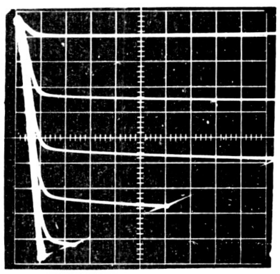
2N1039

#40



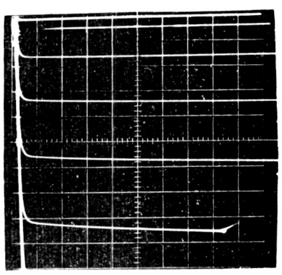
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 100
h_{FE} = 83

Room



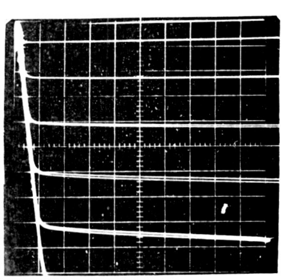
Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 0.5 ma/step
h_{fe} = 88
h_{FE} = 75

Room



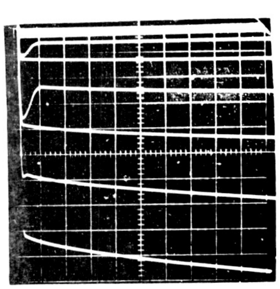
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 2 ma/step
h_{fe} = 2.3
h_{FE} = 1.14

LH_2



Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 5 ma/step
h_{fe} = 8
h_{FE} = 5

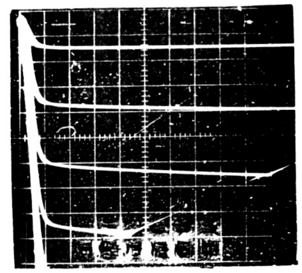
LH_2



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.5 ma/step
h_{fe} = 0.88

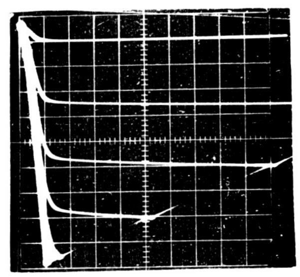
LH_2

#45



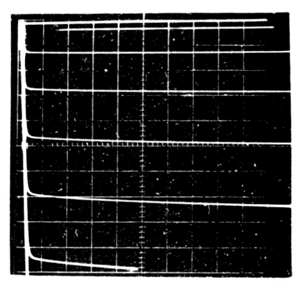
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 104
h_{FE} = 85

Room



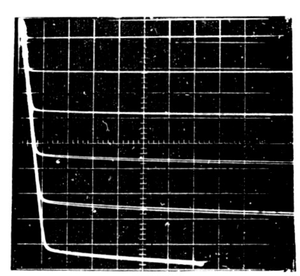
Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 0.5 ma/step
h_{fe} = 95
h_{FE} = 79

Room



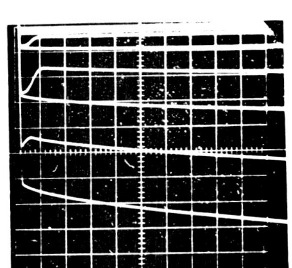
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 2 ma/step
h_{fe} = 2.2
h_{FE} = 0.96

LH_2



Horizontal: 0.2 v/cm
Vertical: 20 ma/cm
Base: 5 ma/cm
h_{fe} = 8
h_{FE} = 5.8

LH_2



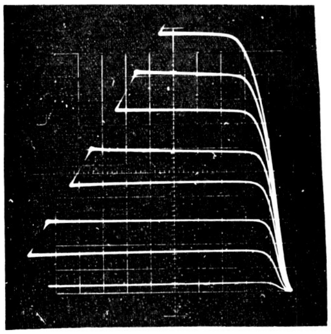
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.5 ma/step
h_{fe} = 0.8

LH_2

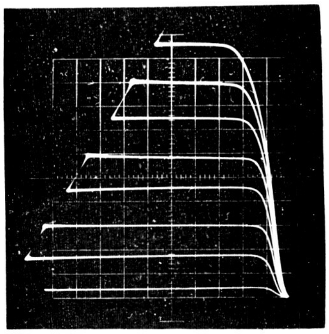
2N760A

Room Temperature
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step

Both transistors failed to operate at liquid hydrogen temperatures.



#2

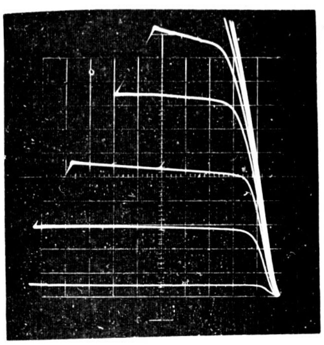


#3

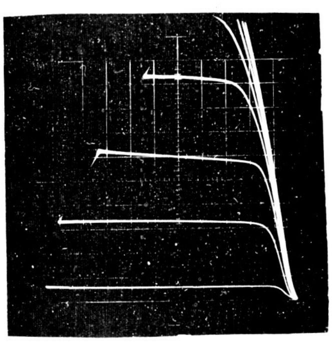
National CG-1

Room Temperature
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step

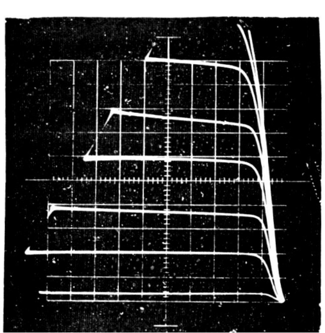
All National CG-1 transistors failed to operate at liquid hydrogen temperatures.



#1



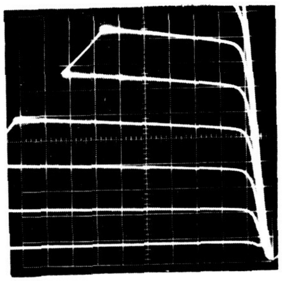
#2



#3

2N1308

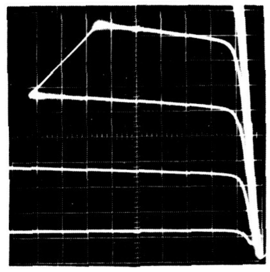
#2



Room

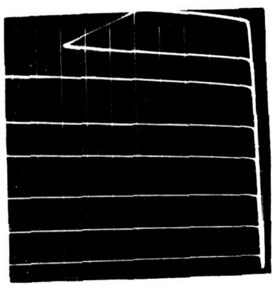
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.02 ma/step
h_{fe} = 180
h_{FE} = 140

#3



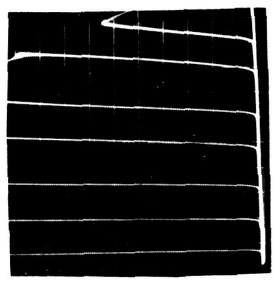
Room

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.02 ma/step
h_{fe} = 280
h_{FE} = 213



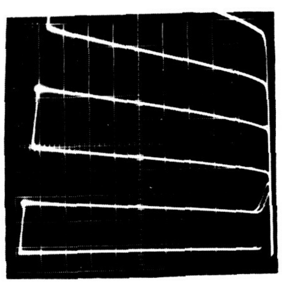
LH_2

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 12
h_{FE} = 12



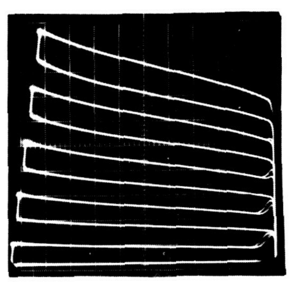
LH_2

Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 15
h_{FE} = 12.7



LH_2

Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 8.8
h_{FE} = 6

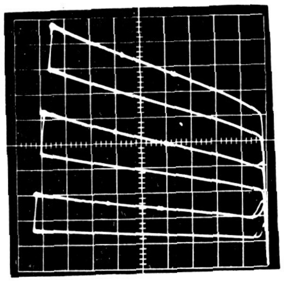


LH_2

Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.02 ma/step
h_{fe} = 9
h_{FE} = 7.4

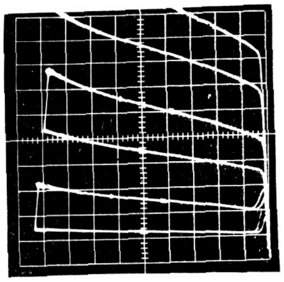
2N1308

Three 2N1308 Transistors
@ Room Temperature



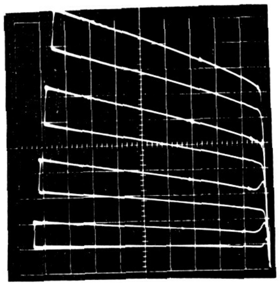
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
h_{fe} = 130
h_{FE} = 130

#1



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
h_{fe} = 180
h_{FF} = 158

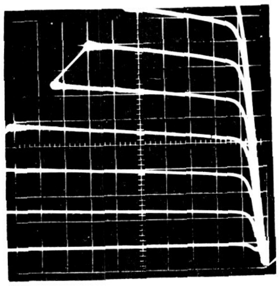
#2



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
h_{fe} = 130
h_{FE} = 130

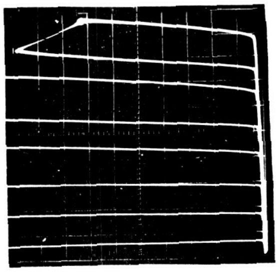
#3

2N1308 #1
Temperature Tests



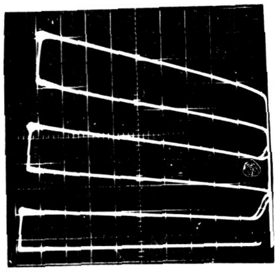
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.02 ma/step
h_{fe} = 160
h_{FE} = 137

Room



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 10
h_{FE} = 10.8

LH_2

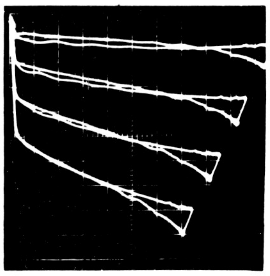


Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 5.6
h_{FE} = 4.8

LH_2

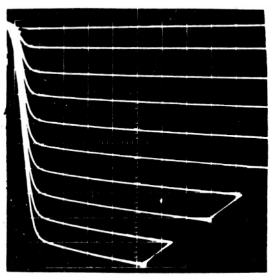
2N1309

#2



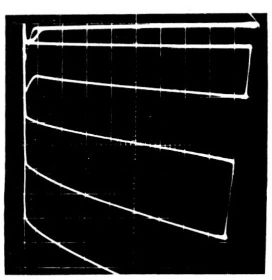
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.001 ma/step
h_{fe} = 190
h_{FE} = 173

Room



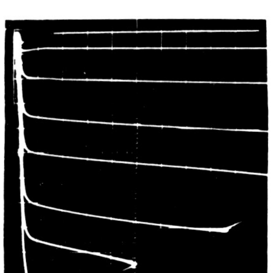
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.01 ma/step
h_{fe} = 190
h_{FE} = 185

Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 10
h_{FE} = 4

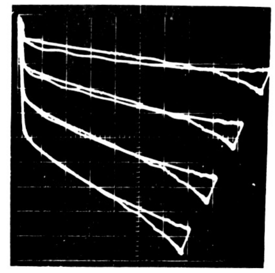
LH_2



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 20
h_{FE} = 10.8

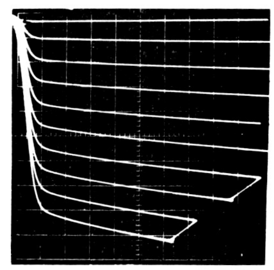
LH_2

#4



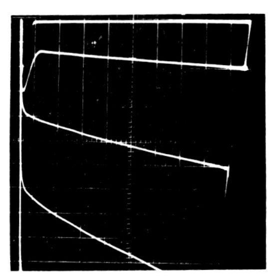
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.001 ma/step
h_{fe} = 200
h_{FE} = 193

Room



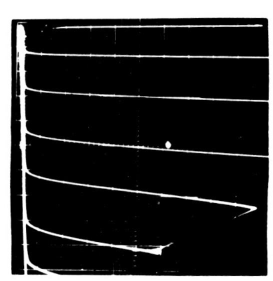
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.01 ma/step
h_{fe} = 200
h_{FE} = 173

Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 16
h_{FE} = 7

LH_2

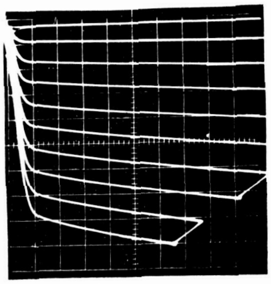


Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 19
h_{FE} = 12.5

LH_2

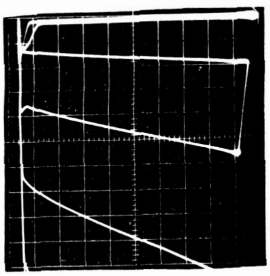
2N1309

#5



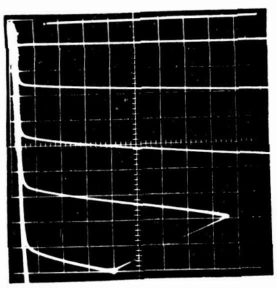
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.01 ma/step
h_{fe} = 200
h_{FE} = 166

Room



Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 14
h_{FE} = 7.1

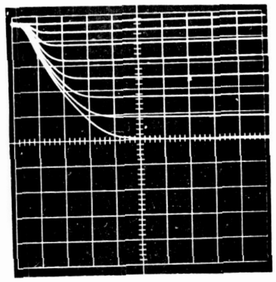
LH_2



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.2 ma/step
h_{fe} = 22
h_{FE} = 13

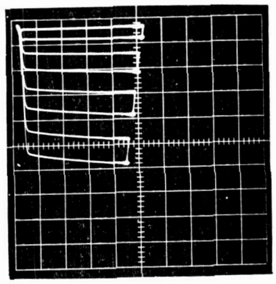
LH_2

2N2189



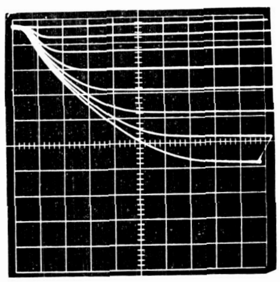
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.01 ma/step
Room Temperature
h_{fe} = 190
h_{FE} = 125

#2



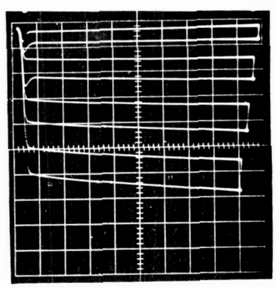
Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
Room Temperature
h_{fe} = 100
h_{FE} = 75

#2



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.01 ma/step
Room Temperature
h_{fe} = 190
h_{FE} = 125

#3

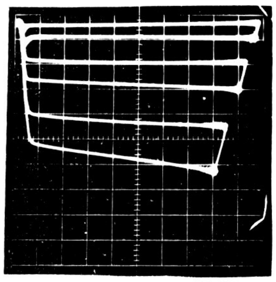


Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.002 ma/step
Room Temperature
h_{fe} = 120
h_{FE} = 85

#3

2N2189

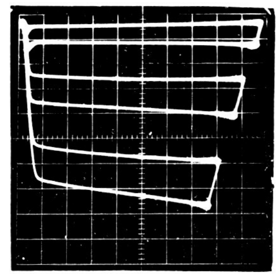
#1



Horizontal: 1 v/cm
Vertical: 1 ma/cm
Base: 0.01 ma/step
h_{fe} = 120
h_{FE} = 96

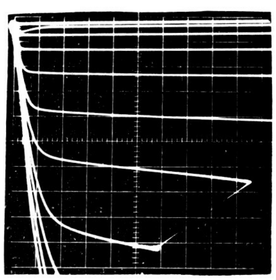
Room

#2



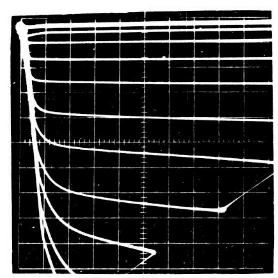
Horizontal: 1 v/cm
Vertical: 1 ma/cm
Base: 0.01 ma/step
h_{fe} = 200
h_{FE} = 116

Room



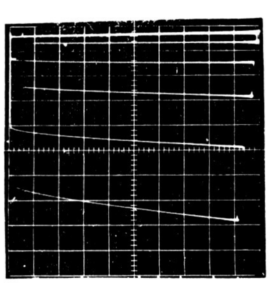
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.1 ma/step
h_{fe} = 40
h_{FE} = 17

LH_2



Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.1 ma/step
h_{fe} = 28
h_{FE} = 15

LH_2

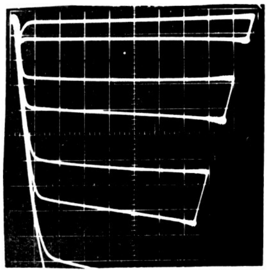


Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.05 ma/step
h_{fe} = 10.8
h_{FE} = 3.6

LH_2

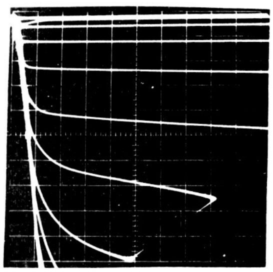
2N2189

#3



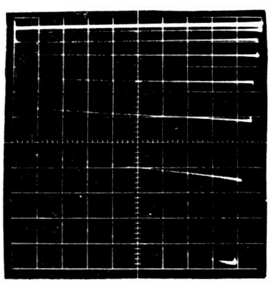
Room

Horizontal: 1 v/cm
Vertical: 1 ma/cm
Base: 0.01 ma/step
h_{fe} = 220
h_{FE} = 105



LH_2

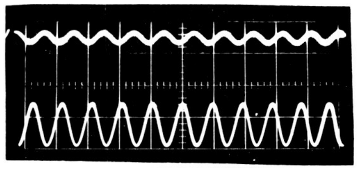
Horizontal: 0.2 v/cm
Vertical: 2 ma/cm
Base: 0.05 ma/step
h_{fe} = 104
h_{FE} = 35.2



LH_2

Horizontal: 1 v/cm
Vertical: 0.2 ma/cm
Base: 0.02 ma/step
h_{fe} = 21
h_{FE} = 18.5

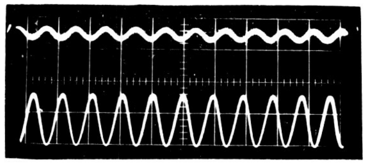
2N2608



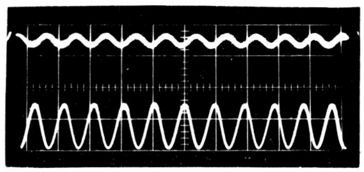
#1

Upper Trace (Input)
0.5 v/cm
Lower Trace (Output)
2 v/cm

All these FET's failed to operate at LH_2 temperatures



#2



#3

APPENDIX II

RESISTOR TEST DATA FOR TEMPERATURE CYCLING TESTS

The data reproduced on the following pages was taken under the test conditions described in paragraph 6.2.5 of this report. The resistance values were measured with a Leeds-Northrup Type 5300 resistance bridge. The metal film resistor data is on pages 2 through 15 while the wire wound resistor data is on pages 16 through 19.

Publication Number 3464-66

THE Bendix CORPORATION

DATE: 9/9/65

ENGINEER: C. Wirtanen PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack TEST LOCATION:

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	9950	9950	9950		9950	9950	9950	9950	9950	9950	9950	9950
2	9930	9940	9940		9940	9940	9940	9940	9940	9940	9940	9940
3	9950	9940	9940		9940	9940	9940	9940	9940	9940	9940	9940
4	9950	9960	9960		9960	9960	9960	9960	9960	9960	9960	9960
5	9980	9970	9970		9970	9970	9970	9970	9970	9970	9970	9970
6	9990	9990	9990		9990	9990	9990	9990	9990	9990	9990	9990
7	10070	10080	10080		10080	10080	10080	10080	10080	10080	10080	10080
8	9970	9980	9980		9980	9980	9980	9980	9980	9980	9980	9980
9	10030	10030	10030		10030	10030	10030	10030	10030	10030	10030	10030
10	9940	9930	9930		9930	9930	9930	9930	9930	9930	9930	9930
11	4970	4970	4970		4970	4970	4970	4970	4970	4970	4970	4970
12	4994	4994	Open		----	----	----	----	----	----	----	----
13	5025	5020	5130		5130	5130	5130	5130	5130	5130	5130	5130
14	4975	4975	4975		4975	4975	4975	4975	4975	4975	4975	4975
15	4970	4970	4970		4970	4970	4970	4970	4970	4970	4970	4970
16	9990	9990	9990		9990	9990	9990	9990	9990	9990	9990	9990
17	9960	9960	9960		9960	9960	9960	9960	9960	9960	9960	9960
18	9970	9970	9970		9970	9970	9970	9970	9970	9970	9970	9970
19	9990	9990	9990		9990	9990	9990	9990	9990	9990	9990	9990
20	9990	9990	9990		9990	9990	9990	9990	9990	9990	9990	9990

Card # 1 25 IRC Metal Film
1/10 Watt Resistors
Vertical Mounting
Circled Numbers Indicate

Teflon Sleeving
20 - 10K Resistors
5 - 4.99K Resistors

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen

PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack

TEST LOCATION:

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
21	9990	9990	9990		9990	9990	9990	9990	9990	9990	9990	9990
22	9970	9970	9970		9970	9970	9970	9970	9970	9970	9970	9970
23	9980	9980	9980		9980	9980	9980	9980	9980	9980	9980	9980
24	9960	9960	9960		9960	9960	9960	9960	9960	9960	9960	9960
25	9970	9970	9970		9970	9970	9970	9970	9970	9970	9970	9970

Card : 1

Form 3020-4-65

DATE: 9/17/65

ENGINEER:

PROJECT: LH_2 Sensor

TECHNICIAN: M. Nowack

TEST LOCATION:

	POTTED		POTTED									
	After 8 cyc	After 9 cyc	After 10 cyc									
1	9950	9950	9950									
2	9940	9940	9940									
3	9940	9940	9940									
4	9960	9960	9960									
5	9970	9970	9970									
6	9990	9990	9990									
7	10080	10080	10080									
8	9980	9980	9980									
9	10030	10030	10030									
10	9930	9930	9930									
11	4970	4970	4970									
12	----	----	----									
13	5130	5130	<u>5140</u>									
14	4975	4975	4975									
15	4970	4970	4970									
16	9990	9990	9990									
17	9960	9960	9960									
18	9970	9970	9970									
19	9990	9990	9990									
20	9990	9990	9990									

Card #1

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen **PROJECT:** LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack **TEST LOCATION:**

	POTTED		POTTED									
	After 8 cyc	After 9 cyc	After 10cyc									
21	9990	9990	9990									
22	9970	9970	9970									
23	9980	9980	9980									
24	9960	9960	9960									
25	9970	9970	9970									

Card #1

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen **PROJECT:** LH Sensor Component Tests

TECHNICIAN: M. Nowack **TEST LOCATION:** 2

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc.	After 1 cyc.	After 2 cyc.	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	2994	2994	2994		2994	2994	2994	2994	2994	2994	2994	2994
2	2986	2986	2986		2986	2986	2986	2986	2990	2990	2990	2990
3	3001	3001	3001		3001	3001	3001	3001	3001	3001	3001	3001
4	2982	2982	2982		2982	2982	2982	2982	2982	2982	2982	2981
5	3007	3007	3007		3007	3007	3007	3007	3007	3007	3007	3007
6	2997	2997	2997		2997	2997	2997	2997	2997	2994	2994	2994
7	2985	2985	2985		2985	2985	2985	2985	2985	2985	2985	2985
8	3000	3000	3000		3000	3000	3000	3000	3000	3000	3000	3000
9	2997	2997	2997		2997	2997	2997	2997	2997	2997	3910	4710
10	3000	3000	3000		3000	3000	3000	3000	3000	3000	3000	3000
11	3009	3009	3009		3009	3009	3009	3009	3009	3009	3009	3009
12	3002	3002	3002		3002	3002	3002	3002	3002	3002	3002	3002
13	2993	2993	2993		2993	2993	2993	2993	2993	2993	2993	2993
14	2997	2999	2999		2999	2999	2999	2999	2999	2999	2999	2999
15	2985	2985	2985		2985	2985	2985	2985	2985	2985	2985	2985
16	3003	3003	3003		3003	3003	3003	3003	3003	3003	3003	3003
17	2990	2990	2990		2990	2990	2990	2990	2990	2990	2990	2990
18	3009	3009	3009		3009	3009	3009	3009	3009	3009	3009	3009
19	2006	2006	2006		2006	2006	2006	2006	2006	2006	2006	2006
20	1998	1998	1998		1998	1998	1998	1998	1998	1998	1998	[illegible]

Card # 2

25 Metal Film 1/10 Watt Resistors
Mounted Vertically
Circled Numbers Indicate Teflon Sleeving
20 - 3 K Resistors
5 - 2 K Resistors

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen

PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack

TEST LOCATION:

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. No.	Orig. Res.	After 2 cy	After 1 cy		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cy	After 5 cyc	After 6 cyc	After 7 cyc
21	2001	2001	2001		2001	2001	2001	2001	2001	2001	2001	2001
22	2005	2005	2005		2005	2005	2005	2005	2005	2005	2005	2005
23	1999	1999	1999		1999	1999	1999	1999	1999	1999	1999	1999
24	3000	3000	3000		3000	3000	3000	3000	3000	3000	3000	3000
25	2999	2999	2999		2999	2999	2999	2999	2999	2999	2999	2999

Card #2

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/10/65

ENGINEER: C. Wirtanen **PROJECT:** LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack **TEST LOCATION:**

	POTTED		POTTED
	After 8 cyc	After 9 cyc	After 10 cyc
1	2994	2994	2994
2	2990	2990	2990
3	3001	3001	3001
4	2981	2981	2981
5	3007	3007	3007
6	2994	2994	2994
7	2985	2985	2985
8	3000	3000	3000
9	8800	Open	----
10	3000	3000	3035
11	3009	3009	3009
12	3002	3002	3002
13	2993	2993	2993
14	2999	2999	2999
15	2985	2985	2985
16	3003	3003	3003
17	2990	2990	2990
18	3009	3009	3009
19	2006	2006	2006
20	1998	1998	1998

Card #2

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen

PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack

TEST LOCATION:

	POTTED		POTTED											
	After 8 cyc	After 9 cyc	After 10 cy											
21	2001	2001	2001											
22	2005	2005	2005											
23	1999	1999	1999											
24	3000	3000	3000											
25	2999	2999	2999											

Card #2

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/10/65

ENGINEER: C. Wirtanen

PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack

TEST LOCATION:

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	5020	5020	5020		5020	5020	5020	5020	5020	5020	5020	5020
2	4973	4973	4973		4973	4973	4973	4973	4973	4973	4973	4973
3	4964	4964	4964		4964	4964	4964	4964	4964	4964	4964	4964
4	5016	5016	5016		5016	5016	5016	5016	5016	5016	5016	5016
5	4977	4977	4979		4979	4979	4979	4979	4979	4979	4979	4979
6	5000	5000	5000		5000	5000	5000	5000	5000	5000	5000	5000
7	4967	4967	4967		4967	4967	4967	4967	4967	4967	4967	4967
8	4990	4990	4990		4990	4990	4990	4990	4990	4990	7940	Open
9	4955	4959	4959		4959	4959	4959	4959	4959	4959	4959	4959
10	5013	5013	5013		5013	5013	5013	5013	5013	5013	5013	5013
11	5013	5013	5013		5013	5013	5013	5013	5013	5013	5013	5013
12	5005	5005	5005		5005	5005	5005	5005	5005	5005	5005	5005
13	4946	4946	4946		4946	4946	4946	5330	5460	5820	5220	5320
14	4963	4963	4963		4963	4963	4963	4963	4963	4963	4963	4963
15	4993	4993	4993		4993	4993	4993	4993	4993	4993	4993	4993

Card # 5

15 IRC Metal Film Resistors, Mounted Horizontally 1/10 Watt
Circled Numbers Indicate Teflon Sleeving
All Are 4990 r

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/17/65

ENGINEER:

PROJECT: LH Sensor

TECHNICIAN: M. Nowack

TEST LOCATION: 2

	POTTED		
	After 8 cyc	After 9 cyc	After 10cyc
1	5020	5020	5020
2	4973	4973	4973
3	4964	4964	4964
4	5016	5016	5016
5	4979	4979	4979
6	5000	5000	5000
7	4967	4967	4967
8	----	----	----
9	4959	4959	4959
10	5013	5013	5013
11	5013	5013	5013
12	5005	5005	5005
13	5320	5200	5330
14	4963	4963	4963
15	4993	4993	4993

Card #5

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/10/65

ENGINEER: C. Wirtanen **PROJECT:** LH Sensor Component Tests

TECHNICIAN: M. Nowack **TEST LOCATION:** 2

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	1998	1998	1998		1998	1998	1998	1998	1995	1995	1995	1995
2	2000	2000	2000		2000	2000	2000	2000	2000	2000	2000	2000
3	1998	1998	1998		1998	1998	1998	1998	1998	1988	1988	1988
4	1995	1995	1995		1995	1995	1995	1995	1995	1995	1995	1995
5	2010	2010	2010		2010	2010	2010	2010	2010	2010	2010	2010
6	1998	1998	1998		1998	1998	1998	1998	1998	1998	1998	1998
7	1996	1996	1996		1996	1996	1996	1996	1996	1996	1996	1996
8	1994	1994	1994		1994	1994	1994	1994	1994	1994	1994	1994
9	2000	2000	2000		2000	2000	2000	2000	2000	2000	2000	2000
10	1988	1988	1988		1988	1988	1988	1988	1988	1988	1988	1988
11	2007	2007	2007		2007	2007	2007	2007	2007	2007	2007	2007
12	1993	1993	1993		1993	1993	1993	1993	1993	1993	1993	1993
13	1992	1992	1992		1992	1992	1992	1992	1992	1992	1992	1992
14	2003	2003	2003		2003	2003	2003	2003	2003	2003	2003	2003
15	1997	1997	1997		1997	1997	1997	1997	1997	1997	1997	1997

Card # 6

15 IRC Metal Film Resistors Mounted Horizontally, 1/10 Watt
Circled Numbers Indicate Teflon Sleeving
All Are 2000 r

Form 3020-4-65

DATE: 9/17/65

ENGINEER:

PROJECT: LH_2 Sensor

TECHNICIAN: M. Nowack

TEST LOCATION:

	POTTED											
	After 8 cyc	After 9 cyc	After 10cyc									
1	1995	1995	1995									
2	2000	2000	2000									
3	1988	1988	1988									
4	1995	1995	1995									
5	2010	2010	2010									
6	1998	1998	1998									
7	1996	1996	1996									
8	1994	1994	1994									
9	2000	2000	2000									
10	1988	1988	1988									
11	2007	2007	2007									
12	1993	1993	1993									
13	1992	1992	1992									
14	2003	2003	2003									
15	1997	1997	1997									

Form 3020-4-65

DATE: 9/14/65

ENGINEER: C. Wirtanen **PROJECT:** LH_2 Sensor

TECHNICIAN: M. Nowack **TEST LOCATION:**

			UNPOTTED		UNPOTTED		UNPOTTED		UNPOTTED		UNPOTTED	
RES. NO.	Orig. Res.	After 1 cyc	After 2 cyc		After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc	After 8 cyc	After 9 cyc	After 10 cyc
1	1001		1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
2	1007		1007	1007	1007	1007	1007	1007	1007	1007	1007	1007
3	1002		1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
4	1010		1010	1010	1010	1010	1010	1010	1010	1010	1010	1010
5	998		998	998	998	998	998	998	998	998	998	998
6	1004		1004	1004	1004	1004	1004	1004	1004	1004	1004	1004
7	1000		1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	1001		1001	1001	1001	1001	1001	1001	1001	1001	1001	1001
9	1002		1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
10	1006	1009	1008	1008	1008	1008	1008	1008	1008	1008	1008	1008

Card # 7

10 IRC Metal Film 1/10 Watt
Resistors, Horizontal
None Teflon Sleeved
All 1 K

Form 3020-4-65

A-II.14

DATE: 9/14/65

ENGINEER: C. Wirtanen **PROJECT:** LH_2 Sensor

TECHNICIAN: M. Nowack **TEST LOCATION:**

			UNPOTTED		UNPOTTED							
RES. NO.	Orig. Res.		After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc	After 8 cyc	After 9 cyc	After 10 cyc
1	1008		1008	1008	1008	1008	1008	1008	1008	1008	1008	1008
2	996		996	996	996	996	996	996	996	996	996	996
3	995		995	995	995	995	995	995	995	995	995	995
4	1007		1007	1007	1007	1007	1007	1007	1007	1007	1007	1007
5	1002		1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
6	993		993	1025	1422	Open	----	----	----	----	----	----
7	998		998	998	998	998	998	998	998	998	998	998
8	1002		1002	1002	1002	1002	1002	1002	1002	1002	1002	1002
9	999		999	999	999	999	999	999	999	999	999	999
10	1003		1003	1003	1003	1003	1003	1003	1003	1003	1003	1003

Card # 8

IRC Metal Film Resistors
1/10 Watt - All Horizontal
<u>All Teflon Sleeved</u>
All 10 K

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/10/65

ENGINEER: C. Wirtanen **PROJECT:** LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack **TEST LOCATION:**

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	2195	2195	2195		2195	2195	2195	2195	2195	2195	2195	2195
2	2200	2200	2200		2200	2200	2200	2200	2200	2200	2200	2200
3	2200	2200	2200		2200	2200	2200	2200	2200	2200	2200	2200
4	2191	2191	2191		2191	2191	2191	2191	2191	2191	2191	2191
5	2200	2200	2200		2200	2200	2200	2200	2200	2200	2200	2200
6	2206	2206	2206		2206	2206	2206	2206	2206	2206	2206	2206
7	2197	2197	2197		2197	2197	2197	2197	2197	2197	2197	2197
8	2197	2197	2197		2197	2197	2197	2197	2197	2197	2197	2197
9	2199	2199	2199		2199	2199	2199	2199	2199	2199	2199	2199
10	2202	2202	2202		2202	2202	2202	2202	2202	2202	2202	2202
11	2197	2197	2197		2197	2197	2197	2197	2197	2197	2197	2197
12	2195	2195	2195		2195	2195	2195	2195	2195	2195	2195	2195

Card # 4

12 Dale 1 Watt Wire Wound Resistors
Mounted Horizontally
Circled Numbers Indicate Teflon Sleeving
All Are 2200 r

Form 3020-4-65

THE Bendix CORPORATION

DATE: 9/17/65

ENGINEER:

PROJECT: LH_2 Test

TECHNICIAN: M. Nowack

TEST LOCATION:

	POTTED		POTTED
	After 8 cyc	After 9 cyc	After 10cyc
1	2195	2195	2195
2	2200	2200	2200
3	2200	2200	2200
4	2191	2191	2191
5	2200	2200	2200
6	2206	2206	2206
7	2197	2197	2197
8	2197	2197	2197
9	2199	2199	2199
10	2202	2202	2202
11	2197	2197	2197
12	2195	2195	2195

Form 3020-4-65

DATE: 9/10/65

ENGINEER: C. Wirtanen

PROJECT: LH_2 Sensor Component Tests

TECHNICIAN: M. Nowack

TEST LOCATION:

	UNPOTTED		UNPOTTED		POTTED		POTTED		POTTED		POTTED	
RES. NO.	Orig. Res.	After 2 cyc	After 1 cyc		After 2 cyc	After 1 cyc	After 2 cyc	After 3 cyc	After 4 cyc	After 5 cyc	After 6 cyc	After 7 cyc
1	2196	2196	2196		2196	2196	2196	2196	2196	2196	2196	2196
2	2195	2195	2195		2195	2195	2195	2195	2195	2195	2195	2195
3	2212	2212	2212		2212	2212	2212	2212	2212	2212	2212	2212
4	2200	2200	2200		2200	2200	2200	2200	2200	2200	2200	2200
5	2201	2201	2201		2201	2201	2201	2201	2201	2201	2201	2201
6	2202	2202	2201		2201	2201	2201	2201	2201	2201	2201	2201
7	2206	2206	2206		2206	2206	2206	2206	2206	2206	2206	2206
8	2200	2200	2200		2200	2200	2200	2200	2200	2200	2200	2200
9	2198	2198	2198		2198	2198	2198	2198	2198	2198	2198	2198
10	2205	2206	2206		2206	2206	2206	2206	2206	2206	2206	2206
11	2196	2197	2197		2197	2197	2197	2197	2197	2197	2197	2197
12	2195	2195	2197		2197	2197	2197	2197	2197	2197	2197	2197

Card # 3

12 Dale 1 Watt Wire Wound
Resistors Horizontally Mounted
Circled Numbers Indicate Teflon Sleeving
All Are 2200 r

Form 3020-4-65

A-II.18

DATE: 9/17/65

ENGINEER: PROJECT:

TECHNICIAN: M. Nowack TEST LOCATION:

	POTTED		POTTED									
	After 8 cyc	After 9 cyc	After 10cyc									
1	2196	2196	2196									
2	2195	2195	2195									
3	2212	2212	2212									
4	2200	2200	2200									
5	2201	2201	2201									
6	2201	2201	2201									
7	2206	2206	2206									
8	2200	2200	2200									
9	2198	2198	2198									
10	2206	2206	2206									
11	2197	2197	2197									
12	2197	2197	2197									

Form 3020-4-65

A-[illegible]

APPENDIX III

ACCEPTANCE TEST DATA ON COMPLETED SENSORS

On the following pages both the acceptance test procedure and the acceptance test data for the 29740-A1 optical liquid level sensor are reproduced. The test results for units serial numbers 509001E, 509002E, and 509003E are given.

Publication Number 3464-66

CODE IDENT. NO. 99251

Bendix Pioneer-Central

ENGINEERING PUBLICATION RELEASE

RELEASE NO. 2781

ATTACHED IS A RELEASED COPY OF: ES-602B DATED 8 June 1966

CONCERNING:

- ☐ Government Specification Modifications to
- ☒ Engineering Specifications
- ☐ Engineering Instructions
- ☐ ____________

APPLICABLE TO:

Optical Liquid Sensor, Type 29740-A1

THE PREVIOUSLY ISSUED COPY OF: ES-602A DATED 26 August 1965

- ☒ Is Superseded by the Attached Copy
- ☐ Is Amended by the Attached Copy
- ☒ Should Be Destroyed
- ☐ Should Be Retained in the File for Reference
- ☐ ____________

CHANGES SINCE PREVIOUS ISSUE:

Paragraphs 3.3.2 and 3.3.3 "Pin B to Pin C shall not exceed 2.5 V DC" was "Pin C to Pin A shall not exceed 0.5 V DC"

Paragraph 3.3.4 "Pin C to Pin A. The ... shall not exceed 0.5 V DC" was "Pin B to Pin C. The ... shall not exceed 2.5 V DC"

Paragraph 3.5 Vacuum of .1 micron or less, was vacuum of 1 atm. (approx.) Added - This test shall be performed within one hour of welding of the back-fill opening

Added Paragraph 3.3.5
Changed Paragraph 3.3.5 to 3.3.6
Changed Paragraph 3.3.6 to 3.3.7

REASONS FOR CHANGES:

To correct errors

APPROVED FOR RELEASE

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ENGINEERING SPECIFICATION

SUBJECT:

Engineering Specification concerning the Optical Liquid Sensor, Type 29740-A1

REQUIREMENTS:

1. General Notes

1.1 Test Conditions - Unless otherwise specified, the following conditions shall exist during all tests:

Barometric Pressure:	29.92 ± 1.00 inches Hg absolute
Room Temperature:	25° ± 5°C
Humidity:	75% or less
Position of Unit Under Test:	Any

1.2 Accuracy of Measuring Devices - All measuring devices shall have an accuracy of 2% or less error.

2. Design and Construction

2.1 The unit shall conform with Pioneer-Central Drawing 29740-0 and all applicable detail and assembly drawings.

3. Individual Tests - Every sensor manufactured to this specification shall be subjected to and meet the requirements of the following individual tests.

3.1 Visual Examination - There shall be no detrimental scratches or rough surfaces on the external surfaces of the sensor. There shall be no evidence of poor workmanship.

3.2 Room Temperature Operation

3.2.1 The sensor shall be energized with 28 V DC and operated with the prism alternately in and out of water.

3.2.1.1 With the prism in liquid and with a load of 600 ohms on the sensor, the voltage measured from pin B to pin C shall not exceed 2.5 volts.

3.2.1.2 With the prism out of liquid and supply voltage applied to pin D, the voltage from pin B to pin C shall not exceed 2.5 volts.

3.2.1.3 With the prism out of liquid and supply voltage removed from pin D, the voltage measured from pin C to pin A shall not exceed 0.5 volts.

3.2.1.4 With the prism in liquid and supply voltage applied to pin E, the voltage from pin C to pin A shall not exceed 0.5 volts.

3.2.2 Repeat Paragraph 3.2.1 for supply voltages of 24 and 32 V DC

3.3 Low Temperature Operation Sensitivity (LN_2)

NOTE: If frost forms on the prism face, the test shall be stopped and the frost removed before resumption of the test.

EC : bdj

3.3.1 The sensor unenergized shall be attached to the mouting hardware which holds the sensor so that its axis is horizontal and the prism edge is vertical. The sensor shall then be lowered slowly into LN_2 which is contained in a blackened insulated vessel.

3.3.2 After being submersed in LN_2 for 20 minutes energize the sensor at 28 V DC. Measure the voltage across the 600 ohm load. The voltage from Pin B to Pin C shall not exceed 2.5 V DC.

3.3.3 Raise the sensor out of the LN_2 and energize the simulated "in liquid" test circuit and measure the voltage across the load. The voltage from Pin B to Pin C shall not exceed 2.5 V DC.

3.3.4 While the sensor is still out of the LN_2 de-energize the test circuit, and measure the voltage drop from Pin C to Pin A. The voltage drop shall not exceed 0.5 V DC.

3.3.5 With sensor in liquid, apply supply voltage to Pin E. The voltage drop from Pin C to Pin A shall not exceed 0.5 volts.

3.3.6 The tests of Paragraph 3.3.2, 3.3.3, and 3.3.4, 3.3.5 shall be repeated for input voltages of 24 and 32 V DC.

3.3.7 Lower the sensor into the LN_2 then raise and lower the sensor slowly to cause the sensor tb switch "In" and "out" of liquid (as noted by monitoring the output). Note the position of the liquid on the prism face when the sensor switches "in" and "out" of liquid. The sensor must switch from "in" to "out" and "out" to "in" within 0.100 inches of the prism center.

3.4 Operation in LH_2

3.4.1 The sensor shall be immersed in LH_2 unenergized for 30 minutes. Then proceed as in Paragraph 3.2.

3.5 Leak Test

Place the sensor under a bell jar and pull a vacuum of 1 micron or less. With a helium leak detector measure and record the leakage rate. The leakage rate shall not exceed 10^{-6} scc/sec. This test shall be performed within one hour of welding of the back-fill opening.

3.6 Insulation Resistance

The minimum resistance between all receptacle pins shorted elect-ically together and the sensor housing shall be 75 megohms when tested at 500 V DC.

3.7 Dielectric Strength

The dielectric strength of the sensor shall not breakdown with 500 V AC (RMS) applied between all receptacle pins shorted electrically together and the sensor housing.

~~EC~~ : ~~bdj~~

DATE: 9/8/65

ENGINEER: C WIRTANEN PROJECT: ES 602A TESTS

TECHNICIAN: TEST LOCATION: ENGINEERING

MFR. NO. : 29740-A1 SER. NO. : 509001E

INSP	PARA. No.		24V		28V		32V					
STP			VBC	VCA	VBC	VCA	VBC	VCA				
610	2.1	CONSTRUCTION										
	3.1	VISUAL INSP.										
	3.2	ROOM TEMP	OPERATION									
	3.2.1.1		1.67V	—	1.83V	—	2.1V	—				
	3.2.1.2		1.64V	—	1.85V	—	2.09V	—				
	3.2.1.3		—	0V	—	0V	—	0V				
	3.2.1.4		—	0V	—	0V	—	0V				
									35	SEP	9 1965	
	3.3	LOW	TEMP.	OPERATION —		LN_2						
	3.3.2		1.72V	—	1.84V	—	2.0V	—				
	3.3.3		1.70V	—	1.84V	—	2.0V	—				
	3.3.4		—	0V	—	0V	—	0V				
	3.3.5		—	0V	—	0V	—	0V				
	3.3.7	SENSITIVITY		IN-TO-OUT		— 1/32	INCH		OUT-TO-IN		0 INCH	
									35	SEP	8 1965	
	3.4	OPERATION	IN LH_2									
	3.4.1		1.7V	—	1.85V	—	2.0V	—				
	3.4.2		1.7V	—	1.85V	—	2.0V	—				
	3.4.3		—	0V	—	0V	—	0V				
	3.4.4		—	0V	—	0V	—	0V	35	SEP	8 1965	

DATE: 9/8/65

ENGINEER: C WIRTANEN　　PROJECT: ES 602A TESTS

TECHNICIAN: ______　　TEST LOCATION: ENGINEERING

MFR. NO. 27740-A1　　SER. NO. 509001E

INSP. STP.	PARA. No.									
201	3.5	LEAK TEST			<2.5 X 10^{-8}		35	SEP	9 1965	
201	3.6	INSULATION RESISTANCE					35	SEP	[illegible] 1965	
201	3.7	DIELECTRIC STRENGTH					35	SEP	[illegible] 1965	

DATE: 9/23/65

ENGINEER: C. WIRTANEN **PROJECT:** ES 602A TESTS

TECHNICIAN: M. NOWACK **TEST LOCATION:** ENGINEERING

MFR. NO. 2974C-A1 SERIAL NO. 50900RE

INSP. STAMP	PARA. No.		24V. V_{BC}	24V. V_{EA}	29V. V_{BC}	29V. V_{EA}	32V. V_{BC}	32V. V_{EA}				
35	2.1		CONSTRUCTION				SEP 24 1965					
35	3.1		VISUAL INSPECTION				SEP 24 1965					
35	3.2		ROOM TEMP OPERATION				SEP 24 1965					
	3.2.1.1		1.76V	—	2.0V	—	2.22V	—				
	3.2.1.2		1.68	—	1.9V	—	2.15V	—				
	3.2.1.3		—	.12V	—	.13V	—	.20V				
	3.2.1.4		—	.12V	—	.13V	—	.18V	SEP 24 1965			
35	3.3		LOW TEMP OPERATION - LN_2									
	3.3.2		1.72V	--	1.9V	—	2.04V	—				
	3.3.3		1.71V	—	1.9V	—	2.0V	—				
	3.3.4		—	0V	—	0V	—	0V				
	3.3.5		—	0V	—	0V	—	0V				
	3.3.7		IN TO OUT +.094		OUT TO IN. +.063					SEP 24 1965		
35	3.4		OPERATION IN LH_2									
	3.4.1		1.73V	—	1.9V	—	2.05V	—				
	3.4.2		1.71V	—	1.87V	—	2.05	—				
	3.4.3		—	0V	—	0V	—	0V				
	3.4.4		—	0V	—	0V	—	0V	SEP 23 1965			

DATE: 9/23/65

ENGINEER: C. WISTANEN PROJECT: E.S. 602A TESTS

TECHNICIAN: M. NOWACK TEST LOCATION: ENGINEERING

MFR No. 29140-01 SERIAL No. 509002E

INSP	PARA. No.											
STAMP												
[illegible]	3.5		HELIUM		LEAK	TEST.	$<2.5 \times 10^{-8}$					
[illegible]	3.6		INSULATION		RESISTANCE.		SEP 24 1965					
[illegible]	3.7		DIELECTRIC		STENGTH.		SEP 24 196[illegible]					

DATE: 10/15/65

ENGINEER: C. WIRTANEN — PROJECT: ES 602A TEST

TECHNICIAN: M. NOWACK — TEST LOCATION: ENGINEERING

MFR. No. 29740-A1 — SERIAL No. 509003E

INSP.	PARA. No.		24V		28V		32V					
STAMP			VDC	VAC	VDC	VAC	VDC	VAC				
	2.1		CONSTRUCTION						OCT 1 8 1965			
	3.1		VISUAL INSPECTION						OCT 1 8 1965			
	3.2		ROOM TEMP. OPERATION						OCT 1 8 1965			
	3.2.1.1		1.80V	—	2.00V	—	2.30V	—				
	3.2.1.2		1.66V	—	1.90V	—	2.13V	—				
	3.2.1.3		—	0.02V	—	0.03V	—	0.05V				
	3.2.1.4		—	0.02V	—	0.03V	—	0.05V				
	3.3		LOW TEMP.		OPERATION		IN LN_2		OCT 1 8 1965			
	3.3.2		1.68	—	1.86	—	2.01	—				
	3.3.3		1.63	—	1.85	—	2.01	—				
	3.3.4		—	0	—	0	—	0				
	3.3.5		—	0	—	0	—	0				
	3.3.7		IN TO OUT	-.015S	OUT TO	IN	-1.031S					
	3.4		OPERATION		IN LH_2				OCT 1 8 1965			
	3.4.1		1.76V	—	1.95V	—	2.1V	—				
	3.4.2		1.76V	—	1.93V	—	2.07V	—				
	3.4.3		—	0V	—	0V	—	0V				
	3.4.4		—	0V	—	0V	—	0V				

DATE: 9/15/65

ENGINEER: C. WIRTANEN

PROJECT: ES 602A TEST

TECHNICIAN: M. NOWACK

TEST LOCATION: ENGINEERING

MFR. No. 29740-A1 SERIAL No. 509C03E

INSP. STAMP	PARA. No.												
35	3.5		HELIUM LEAK CHECK <2.5 x 10⁻⁸ OCT 1 8 1965										
35	3.6		INSULATION RESISTANCE OCT 1 8 1965										
35	3.7		DIELECTRIC STRENGTH OCT 1 8 1965										